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1 INTRODUCTION

Hyperion is a hyperspectral instrument on the Earth-Observing 1 (EO-1) spacecraft that was launched from Vandenberg Air Force Base on November 21, 2000. EO-1 is part of NASA's New Millennium Program, which is an initiative to demonstrate advanced technologies for dramatically reducing the cost and improving the quality of instruments and spacecraft for future space missions. Under this program, missions are intended to validate new technologies in flight and to provide useful scientific data to the user community. The primary demonstrations are oriented towards remote sensing technologies, and spacecraft technologies that will be used in defining future Landsat type missions. The instrument payloads on the spacecraft are Hyperion, ALI (Advanced Land Imager) and AC (atmospheric corrector). The first three months of the mission life were focused on instrument activation and performance verification.

This document EO-1/ Hyperion Science Data User's Guide introduces the user to the Hyperion data set, details the data processing steps, and highlights performance characteristics from the standpoint of the user.

Revision A of this document includes the description of the release of Revision A of the Level 1 processing code, Level 1_A. The Level 1 code was updated to Level 1_A in response to Science Validation Team data needs and in response to knowledge gained during the Hyperion on-orbit performance verification period. The full list of changes incorporated in Level 1_A is provided in Section 3.5.1. Level 1 processing with the Level 1_A code began in July 2001. Timed with the release of the Level 1_A code was an update to the calibration file HypGain to HypGain_RevA. The revision of the calibration file was an update to the method used to process the data used to generate the pre-flight calibration file. The revision improved the agreement in the VNIR – SWIR spectral overlap region, and extended the calibrated spectral range down to 400 nm. Subsequent changes in echo correction parameters, calibration file, and bad pixel list are tracked using numbers in the data file appendages, i.e., .L1_A, .L1_A1, .L1_A2, and L1_A3. A "readme" file has been developed to track changes in the code as well as changes in the echo correction file, ratio.txt, and the calibration file. The current version of the "readme" file is "L1readme_r3.xls" which has been made available to the EO-1 Science Team for ready reference, and has been attached to this document as Appendix 1. Updates of this file are prepared and sent to the EO-1 Mission Science Office for dissemination.

Revision B of this document includes a description of Revision B of the Level 1 processing code, Level 1_B. The Level 1_A code was updated to Level 1_B in response to a request from NASA/GSFC to incorporate co-registration of the VNIR and SWIR data. Processing with the Level 1_B code began in November 2001.

1.1 Document Scope

The goal of this document is to assist the user in most effectively exploring the Hyperion data set.

The document is organized into four chapters. This chapter, Chapter 1: Introduction provides a general overview of the EO-1 Mission, an overview of the Hyperion instrument and a review of the Hyperion instrument requirements. This chapter also introduces the users to the Hyperion data collection event (DCE) sequence and highlights the flow of the data from the spacecraft to the users. A contact list is provided further support.

Chapter 2: Hyperion Data Cube Quick Start provides the user with some quick steps to allow the user to become familiar with the data. The discussion assumes the user is using ENVI and that the

user is reviewing the Hyperion Level 1 processed data having a .L1_B extension, (also applicable to .L1 and .L1_A extensions). The chapter recommends VNIR and SWIR bands for grayscale and RBG quick look images. The chapter introduces the user to the Hyperion spectra. A brief discussion is provided in the last section for those who may use other software for processing and data analysis. The full discussion of how to use the Hyperion data set is deferred to chapter 4.

Chapter 3: Hyperion Data Collection, Flow and Processing describes the data collection event sequence and the types of data collection events that are available. The data flow from user request through shipment of data to the user is highlighted. Further details of the level 0 and level 1 processing are discussed. For the level 1 (.L1, .L1_A, and .L1_B) processing discussion, the steps as well as the data files that are created at each step of the processing sequence are presented.

Chapter 4: Hyperion Data Cube Details describes the derivation and verification of the absolute radiometric calibration and spectral calibration. The section on advanced topics presents additional details. The details are required to properly use the absolute and spectral calibration.

Chapter 5: End-to-End Measurement Accuracy describes the Hyperion end-to-end error budget.

1.2 EO-1/ Mission Overview

The responsibility of NASA's Mission to Planet Earth is to ensure the continuity of future Landsat data and the improvement of Earth Science information for better understanding of our planet. The New Millennium Program's (NMP) Earth Orbiter 1 (EO-1) serves both of these responsibilities: EO-1 Advanced Land Imager (ALI) validates technologies which could provide cost reductions for future Landsat missions and the Hyperion instrument provides a new class of earth observation data for improved Earth surface characterization. For the latter, the primary goal of the Hyperion is to provide a science grade hyperspectral instrument with quality calibration based on existing critical designs and existing selected hardware. Hyperion also supports the evaluation of ALI, LAC, and comparison with LANDSAT ETM+.

The EO-1 has a sun-synchronous orbit with an altitude of 705 km and a 10:01 AM descending node. The orbit inclination is 98.2 degree, the orbital period is 98.9 minutes, and the EO-1 equatorial crossing time is one minute behind Landsat-7. The velocity of the EO-1 nadir point is 6.74 km/sec. Figure 1 depicts the formation flying capability of the EO-1 spacecraft. Also depicted is the overlay of the swath width for the different instruments.

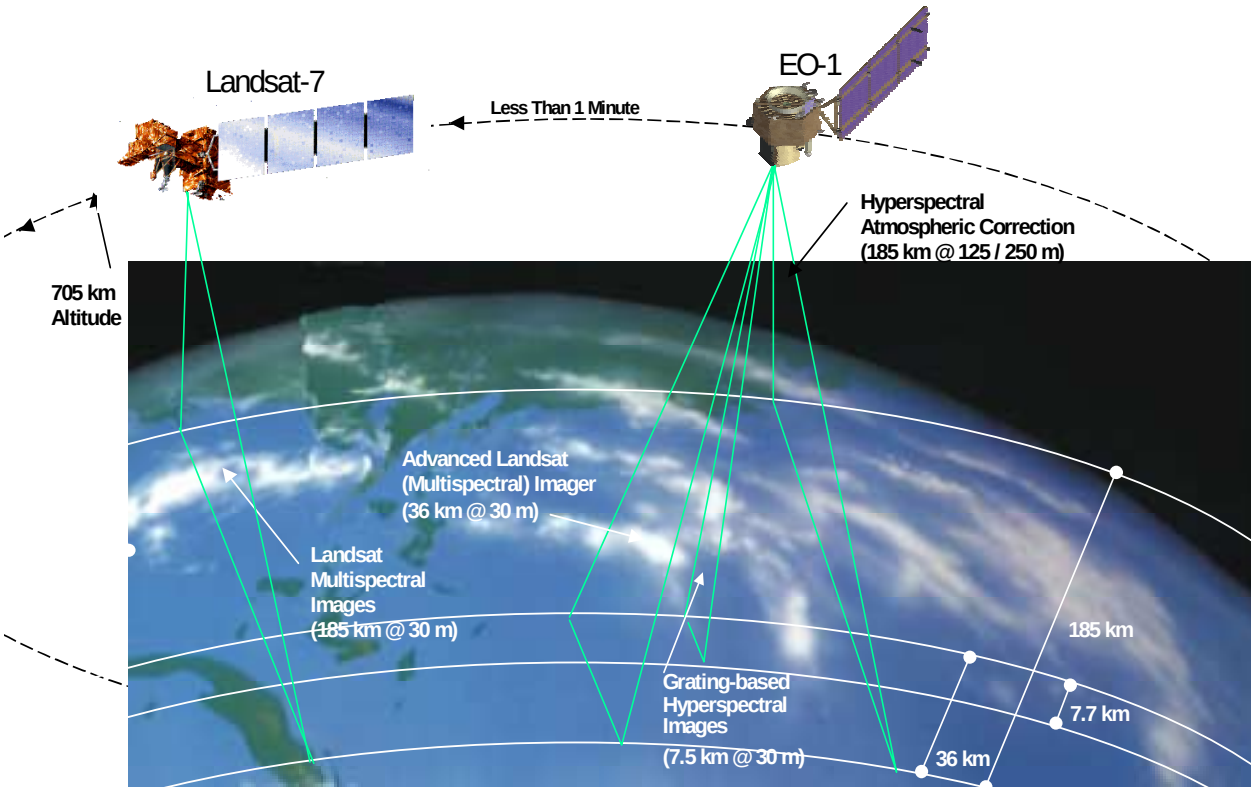

Figure 1: Schematic of the satellite constellation. This figure shows the overlap and dimensions of the groundtracks for Landsat 7 and the three EO-1 instruments, Hyperion, Advanced Landsat Imager, and the Atmospheric Corrector. Note that EO-1 follows one minute behind Landsat in the Landsat orbit.

1.3 Hyperion Instrument Overview

The Hyperion instrument provides radiometrically calibrated spectral data. The purpose of the data is to support evaluation of hyperspectral technology for Earth observing missions. Hyperion is a pushbroom, imaging spectrometer. Each ground image contains data for a 7.65 km wide (cross-track) by 185 km long (along-track) region. Each pixel covers an area of 30 m x 30 m on the ground, and a complete spectrum covering 400 – 2500 nm is collected for each pixel. Since Hyperion is a pushbroom system the entire 7.65 km wide swath is obtained in a single frame. The 30 m size in the along-track direction was obtained by basing the frame rate on the velocity of the spacecraft for a 705 km orbit.

Hyperion has a single telescope and two spectrometers, one visible/near infrared (VNIR) spectrometer and one short-wave infrared (SWIR)) spectrometer. The Hyperion instrument, Figure 2, consists of 3 physical units: 1) the Hyperion Sensor Assembly (HSA), 2) the Hyperion Electronics Assembly (HEA), and 3) the Cryocooler Electronics Assembly (CEA). The HSA, Figure 3, includes subsystems for the telescope, internal calibration source, the two grating spectrometers and the supporting focal plane electronics and cooling system. The telescope images the Earth onto a slit that defines the instantaneous field-of-view which is 0.624 deg wide (i.e., 7.65 Km swath width from a 705 Km altitude) by 2.44 $x10^{-3}$ deg (30 meters) in the satellite velocity direction. This slit image of the Earth is relayed to two focal planes in the two grating spectrometers. A dichroic filter in the system reflects the spectral region from 400 to 1,000 nm to a VNIR spectrometer and transmits the region from 900 to 2500 nm to a SWIR spectrometer. The HEA contains the interface and control electronics for the instrument and the CEA controls

cryocooler operation. These units are all placed on the nadir-facing deck of the spacecraft with the viewing direction as shown in Figure 4.

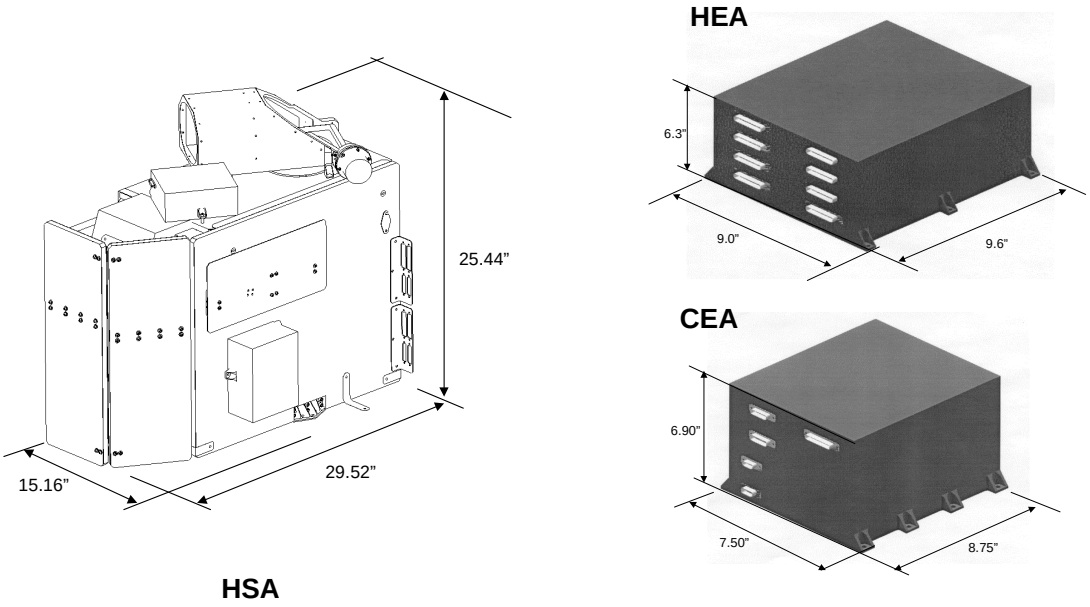

Figure 2: Drawing of Hyperion Instrument and Electronics

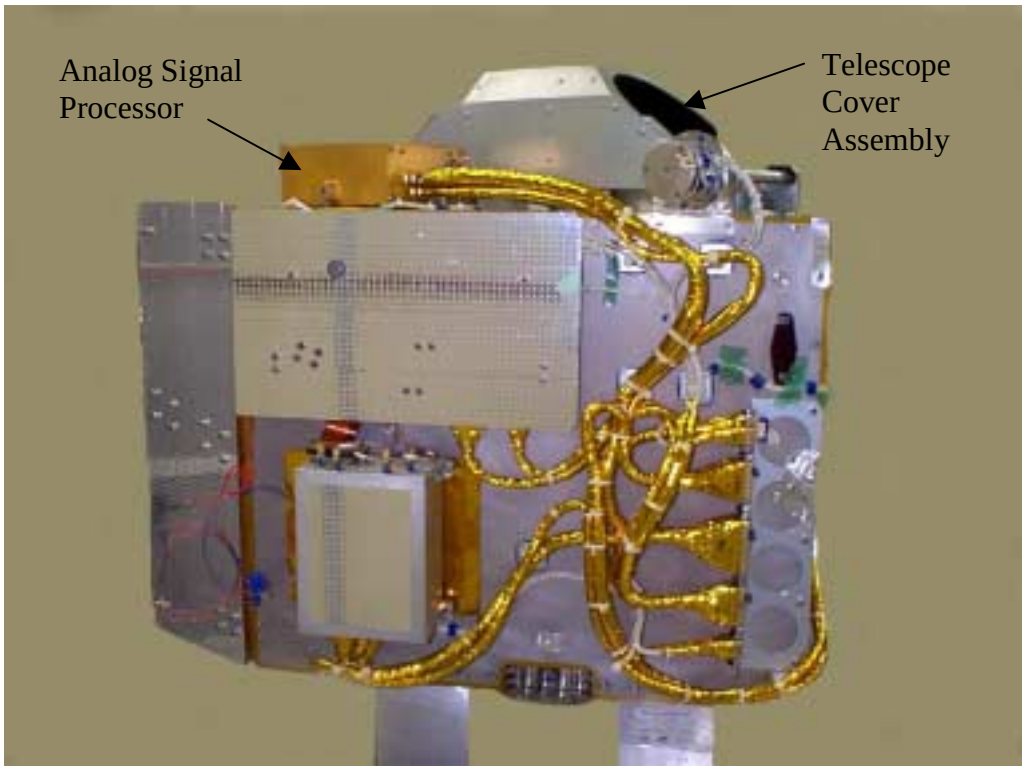

Figure 3 : Photo of the Hyperion Sensor Assembly (HSA)

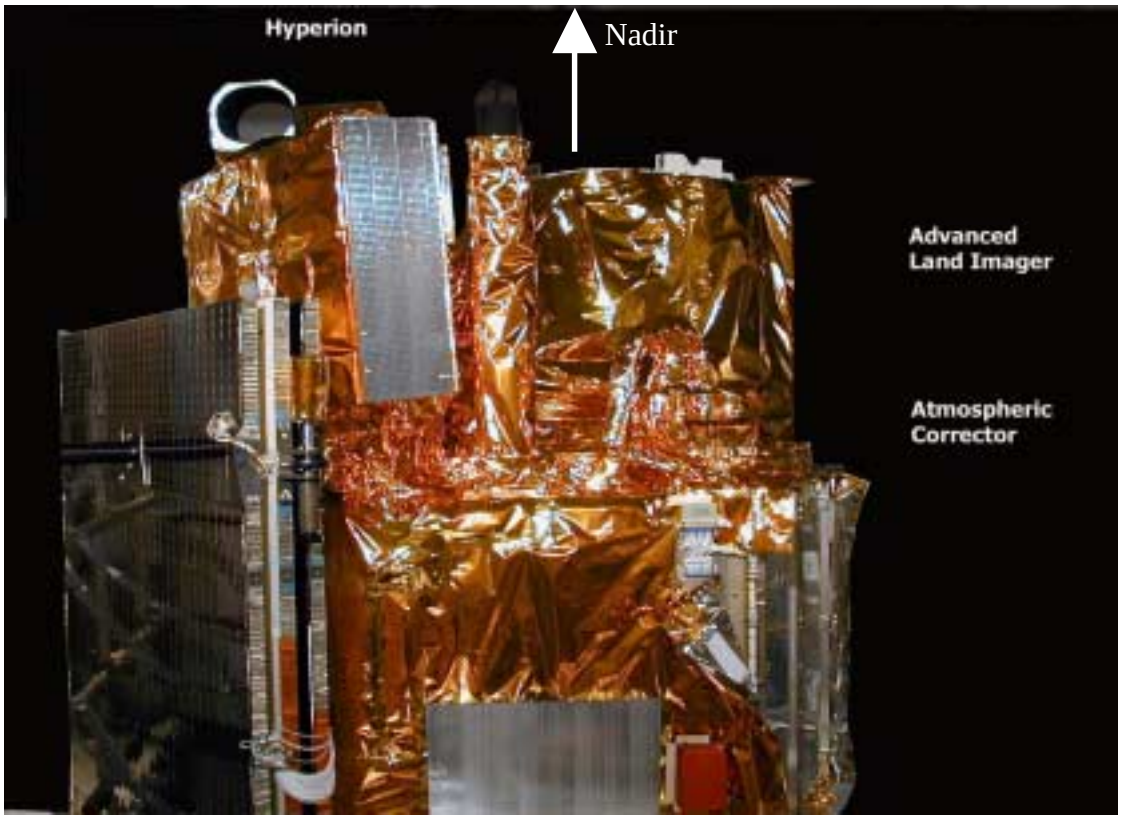

Figure 4: Photo of Hyperion as mounted on the EO-1 spacecraft

The HSA consists of an enclosure providing thermal control for the Opto-Mechanical Subsystem (OMS) on which are mounted the VNIR and the SWIR Focal Plane Arrays (FPAs). The OMS consists of the telescope, the VNIR spectrometer and the SWIR spectrometer. The HSA enclosure is the mounting interface between the HSA and the spacecraft, and has a motorized aperture cover. The HSA enclosure also provides support for the pulse tube cryocooler, the VNIR and the SWIR Analog Signal Processors (ASP), and the in-flight calibration source (IFCS). The SWIR FPA is cooled by a cryocooler. The VNIR FPA is cooled by a radiator. The IFCS consists of a lamp to illuminate the backside of the aperture cover, which is a diffuse reflector (white paint). In addition, with the aperture cover partially open, solar illumination of the diffuse reflector provides a second method for on-orbit radiometric verification.

1.4 Summary of Hyperion Performance Characteristics

The Hyperion instrument team verified instrument performance during the first three months of the EO-1 mission. The assessment focused on determining whether the pre-flight Hyperion characterization was still applicable to on-orbit operations. In addition, science data was reviewed in detail to quantify the impact of the instrument characteristics on user applications. The instrument performance was compared with requirements and pre-flight measurements. Tables 1-3 present summaries of the instrument performance and include Radiometric Performance, Spectral Performance and Image Quality Performance, respectively. Each table contains the pre-flight value, and the on-orbit value. The EO-1/ Hyperion Early Orbit Checkout Report : Part II On-Orbit Performance Verification and Calibration documents the analysis.

The on-orbit assessment concluded that the pre-flight characterization was valid for on-orbit operation. The pre-flight absolute calibration file was adjusted for pixel-to-pixel variations based on an updated analysis of pre-flight results and accepted for on-orbit operation. The spectral calibration was verified for on-orbit operation.

Table 1 presents the results from the radiometric performance evaluation. The signal-to-noise ratio (SNR) exceeds the requirement for all wavelengths, while the absolute accuracy meets the requirements.

Table 1: Radiometric Performance

	Spectral Range	**Pre-Flight**	**On-Orbit**
Absolute Radiometry (end-to-end)	VNIR	< 6%	consistent with preflight
	SWIR	<6%	consistent with preflight
SNR	550 nm	150	192
	650 nm	140	140
	700 nm	140	140
	1025 nm	90	65
	1225 nm	110	96
	1575 nm	89	64
	2125 nm	40	38
Quantization	All	12 bit	12 bit

Table 2 presents the results of the spectral performance. There are 220 unique spectral channels. The baseline Level 1 processing calibrates 200 unique spectral channels, and has an additional 4 channels of overlap. Spectral bandwidths were measured precisely during TRW ground testing. Direct on-orbit measurements of these values were not attempted. A technique using an atmospheric limb data collect was developed to verify the center wavelengths for the VNIR and SWIR spectral channels. The number of spectral features in the SWIR portion of the data, due to the combination of atmospheric lines and lines on the diffuse reflectance panel, enabled verification of the center wavelength for the entire SWIR to ±3 nm. Although the number of available lines in the VNIR was more limited, it was determined that the pre-flight VNIR spectral calibration was still valid. The results of the center-wavelength verification were used to determine the cross-track spectral error and the dispersion. The on-orbit measurements verify the ground measurement to within the measurement accuracy for both VNIR and SWIR.

Table 2: Spectral Performance

	Instrument Parameter	**Pre-Flight**	**On-Orbit**
Number of Spectral Channels	VNIR & SWIR	220	220 200 selected for Level 1 processing
Spectral Range		357-2576 nm center wavelengths determined to ± 1 nm	357-2576 nm, 400-2400 nm selected for Level 1 processing

	Instrument Parameter	**Pre-Flight**	**On-Orbit**
Spectral Bandwidth	VNIR	10.08–10.09 nm	Not measured
" "	SWIR	10.11-10.13 nm	Not measured
Cross Track Spectral Error	VNIR	2.57-3.59 nm	1.71-2.55 nm
" "	SWIR	.17-.98 nm	.40-.97 nm

Table 3 presents results for the Image Quality parameters. The measured Ground Sample Distance (GSD) at nadir was 30 meters as predicted from pre-flight measurements. There are 256 field-of-view locations that comprise the swath width. This corresponds to a 7.75 km swath width per focal plane. However, there is a 1-pixel cross-track pixel difference between the VNIR and SWIR, which reduces the swath width by one GSD (255 pixels used). The VNIR-SWIR Modulation Transfer Function (MTF) was measured on-orbit and the results were similar to the pre-flight measurements. Spatial co-registration is a measure of an object's position as a function of spectral band within the focal plane. The characterization of the VNIR and SWIR spatial co-registration of spectral channels was within the on-orbit measurement accuracy. In this case, the on-orbit status is considered to support the pre-flight characterization. The VNIR-SWIR spatial co-registration is discussed further in chapter 4.

Table 3: Image Quality Performance

	Instrument Parameter	**Pre-Flight**	**On-Orbit**
GSD (nadir)	Entire Range	29.88 m	30.38 m
Swath Width	Entire Range	7.75 km (per focal plane)	7.75 km (per focal plane)
MTF (In-Track)	450 nm	.22-.29 meas. @ 500nm	.23-.27 meas. @ 500nm
	630 nm	.22-.27	.23-.27
	900 nm	.22-.24	.24-.28
	1250 nm	.27-.30	.20-.25
	1650 nm	.25-.27	.28
	2200 nm	.23-.28	Not measured
VNIR spatial Co-Registration	All	10-25% of pixels	Consistent with pre-flight, 10-30% of pixel
SWIR spatial Co-Registration	All	18-28% of pixels	Consistent with pre-flight, 25% ±. 15% of pixel

1.5 Overview of Hyperion Data Collection and Data Flow

A Hyperion science data collection event (DCE) consists of 5 files. In order of collection this includes pre-image dark collect, image collect, post-image dark collect, internal calibration lamp collect, post-lamp dark collect. The dark collects are 1 second each, the lamp collect is 3 seconds

and a typical image collect is 30 seconds with the desired scene being contained in the centered 24 seconds. The process takes about 15 minutes with the longest time being the 10 minute wait after the instrument is commanded from Idle to Standby to allow the ASPs to achieve thermal stability before the pre-image dark, and the 3 minute wait after the internal calibration lamp is turned on to allow the lamp output to stabilize. The instrument is commanded into Imaging from Standby mode and returns to Idle mode after the post-lamp dark collect. The instrument is in Standby mode only during DCEs. The remainder of the time the instrument is in Idle mode. The instrument returns to Idle mode after the post-lamp dark collect. Further details of the DCE timeline are discussed in chapter 3.

The Hyperion science data and ancillary data obtained during a DCE is stored on the Wideband Advanced Recorder Processor (WARP). The Hyperion science data includes the 5 data files described above and the ancillary data refers to the instrument telemetry obtained during the DCE. The WARP also stores science data from the other instruments as well as ancillary data from the other instruments and select subsystems. The science data and ancillary data are downlinked to one of several ground stations using an X-band downlink. All of this data is recorded on Ampex tape and sent to GSFC by the ground stations. The data flow at GSFC is shown in Figure 5. GSFC performs Level 0 processing on the data. Description of this processing is provided in chapter 3. GSFC sends the Level 0 data and ancillary data, on a Digital Linear Tape (DLT) to TRW. TRW performs Level 1 processing on requested DCEs. Level 1 processing produces metadata files that can be used to track the processing steps as well as give an indication on the quality of the Level 1 data product. TRW sends the Level 1 data and the metadata files to GSFC on a DLT. This is described in more detail in chapter 3. GSFC handles the distribution of the data to the users. Level 1 processing prior to July, 2001 produced files with the extension .L1. Level 1 processing began using Rev A of the Level 1 code at the beginning of July, 2001, which produces image files with the extension .L1_A. Level 1 processing began using Rev B of the level 1 code on 15 November, 2001, which produces image files with the extension .L1_B.

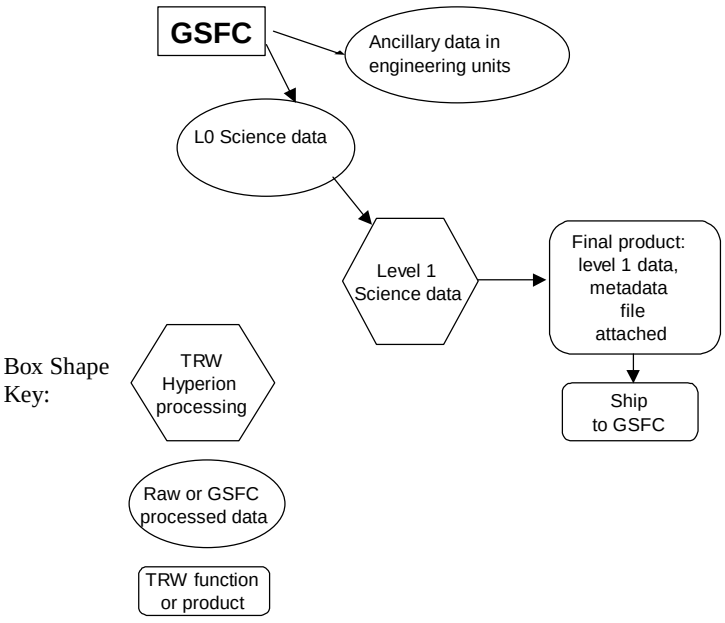

Figure 5: Hyperion Data Flow from GSFC to TRW

Nominally it takes GSFC 3-5 days from receipt of the raw data to perform Level 0 processing and deliver the tapes to TRW. TRW performs Level 1 processing and ships the final Level 1 data product with metadata files for select DCEs to GSFS within 3 days of receipt of the Level 0 data. The length of time from DCE downlink to level 1 processed-data typically varies from 1.5 to 3 weeks depending on the ground station used because of the length of time it takes to get data tapes from the ground station to GSFC using surface mail.

1.6 Hyperion Contact List

The following contact information is provided for Hyperion related questions.

Debra Beiso	310 812-5244 debra.beiso@trw.com	Hyperion Performance Analysis and Data Processing
Mr. Steve Carman	310 812 0279 steve.carman@trw.com	Hyperion Program Manager
Dr. Jay Pearlman	310 812 0337 jay.pearlman@trw.com	EO-1 Program Support, Science and Mission Operations
Dr. Carol Segal	310 813 0229 carol.segal@trw.com	Hyperion Deputy Program Manager, Mission Operations and Planning

There are many supporting documents for the Hyperion instruments. This includes memos addressing instrument performance as well as papers prepared for journal and conference publication. The user should contact Carol Segal for requests of supporting documentation.

2 HYPERION DATA CUBE QUICK START

This chapter is designed to provide the user with some quick steps to get familiar with the data. The discussion assumes that the user is using the Hyperion Level 1 processed data. The file should be the Level 1 radiometrically-calibrated data with a .L1_B extension. Data processed prior to July 1, 2001 will have a .L1 extension, data processed prior to November 15, 2001 will have a .L1_A extension. This description is geared towards users who are using ENVI. A brief discussion is provided in the last section for those who may use other software for processing and data analysis. The user will typically receive the Level 0 files before the Level 1 processed file. The Level 0 data set is described in chapter 3.

2.1 Data Cube Structure

A typical Hyperion image has the dimensions of 256x6925x242. The first number represents the number of pixels that span the field of view. The span of the field-of-view defines the swath width. One entire swath width of data is obtained for each frame. The total number of frames is represented by the second dimension and defines the swath length. The instantaneous field of view for each pixel and the frame rate, 223.4 Hz, define the dimensions of ground being imaged. Each pixel location images approximately a 30 m by 30 m region of the ground. The swath width for each focal plane is comprised of 256 pixel locations corresponding to 7.7 km. There is a 1-pixel shift between the VNIR and SWIR cross track co-registration, resulting in a 255 VNIR-SWIR coincident field-of-view locations. For each pixel location, 242 spectral channels of data are

obtained. Spectral channels from 1-70 are collected from the VNIR and channels 71-242 are collected from the SWIR. Due to low signal for some channels, and to reduce duplication in the VNIR-SWIR overlap region, some of these spectral channels are not calibrated. The uncalibrated channels are set to zero. The "zero-ed" channels are not removed from the file so the final data set is the same size as the initial data set.

There are three versions of the Hyperion Level 1 data product, suffixes .L1, .L1_A and .L1_ B, so the header and the data file extension should be reviewed to determine which data product is being analyzed.

Original level 1: The data is an unsigned integer. The data is presented as calibrated radiance (W/m2-sr-um) times a factor of 100 for both the VNIR and the SWIR. The calibrated data file has the extension .L1.

Revision A: The data is a signed integer. A scaling factor has been applied to the calibrated radiance (W/m2-sr-um). A factor of 40 was applied to spectral bands 1-70, and a factor of 80 was applied to spectral bands 71-242. To obtain data in units of (mW/cm2-sr-um), the data should be multiplied by 10^{-1}. The extension to the calibrated data file is .L1_A. The header file will also indicate the version of the processing code as well as the factors used for the VNIR and SWIR bands.

Revision B: The SWIR and VNIR components of the data have been spatially co-registered in the cross-track and along-track dimensions. An additional metadata file, a text file with the extension .aln.log, indicates the source file and the output file names for the final co-registered data product, .L1_B.

2.2 Suggested Band Combinations for Images

Using ENVI the following is suggested for quick viewing of the Hyperion data. Example images are provided after the discussion. It should be noted that, unless you are using level 1_B data, there is a spatial offset between the VNIR and the SWIR. So unless the appropriate shifts are made, RGB images should be limited to only VNIR bands or only SWIR bands.

2.2.1 VNIR Band 40 or SWIR Band 93

A simple and reliable way to get a quick feel for the contents of the image is to display a gray scale image of Band 40. This band in the VNIR corresponds to 753 nm. SWIR band 93 at 1074 nm can be used for the SWIR. Figure 6 is an example of Band 40 and Band 93 for the San Francisco Salt Pond data collection event obtained on January 17, 2001. The entire swath width is displayed, but only a subset of the swath length is presented in these images. When reviewing single bands, streaks in the vertical direction may be noticed. The phenomena are caused by a variation in the calibration of the pixels in the cross-track direction. Small pixel-to-pixel variations are more noticeable in uniform scenes. This topic is discussed further in chapter 4.

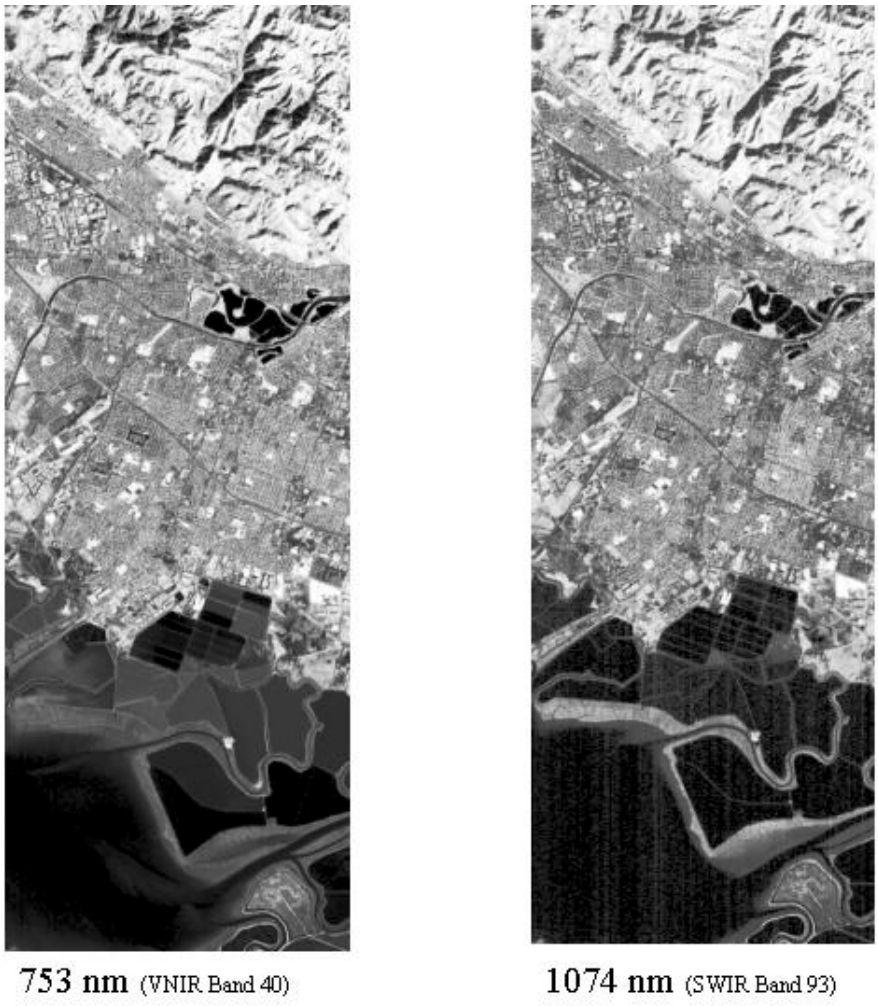

Figure 6: Example Gray Scale display of Hyperion data, San Francisco Salt Ponds 1-17-01

2.2.2 VNIR: visible RGB

To obtain a color image of the scene that represents true RGB the bands 29:23:16 for R:G:B are typically used. This band combination corresponds to approximate wavelengths of 641 nm, 580 nm and 509 nm. Slight variations in the bands selected will not noticeably affect the RGB image. Figure 7 displays an example of a visible RGB for the San Francisco Salt Pond data collection event obtained on January 17, 2001.

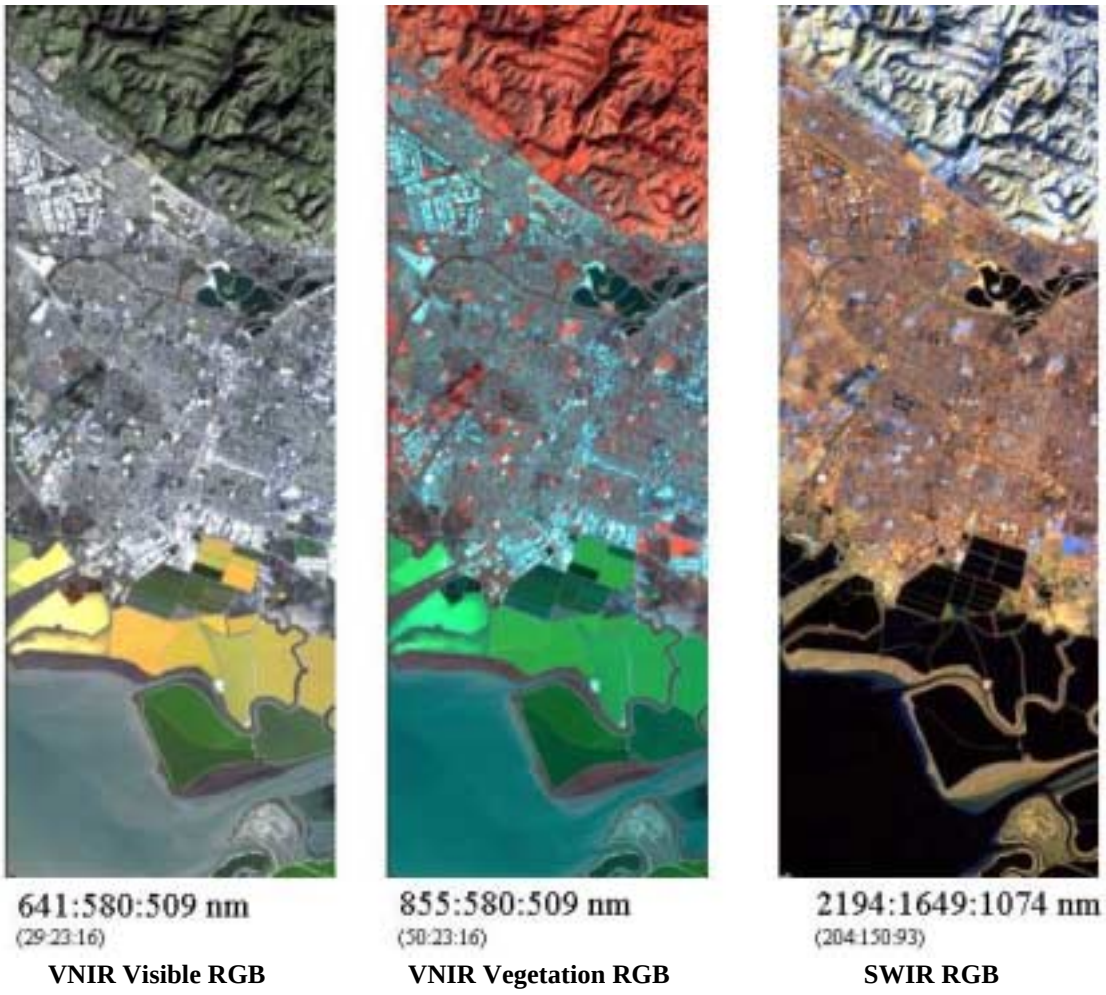

Figure 7: Example of RGB viewing of Hyperion Data, San Francisco Salt Ponds 1-17-01

2.2.3 VNIR: vegetation RGB

To obtain a color image of the scene in which vegetation appears red, bands 50:23:16 can be selected. This band combination corresponds to approximately 855 nm, 580 nm and 509 nm. Slight variations in the bands selected will not noticeably affect the RGB image. See Figure 7 for an example.

2.2.4 SWIR: RGB

To obtain a color image of the SWIR, bands 204:150:93 for R:G:B is a usable combination. The corresponding wavelengths are 2194 nm, 1649 nm and 1074 nm. These bands are outside of the region of the spectrum that is most significantly affected by atmospheric absorption. See Figure 7 for an example. When using the SWIR data it is important to know if the SWIR was at the proper operational temperature. The proper operational temperature is when the SWIR FPE temperature is –153.5 ± 1C. An HDF file delivered with the Hyperion data contains this parameter. This is discussed further in chapter 3. The absolute calibration for the SWIR is only applicable at the operational temperature. The SWIR has negligible response when too warm. If the SWIR image does not contain features consistent with the VNIR image then the SWIR was quite possibly not at the operational temperature. However, it may not be clearly evident from the image if the SWIR is

slightly off operational temperature. The SWIR FPE temperature is maintained by a cryocooler. Due to operational constraints, the cooler does not run continuously. A table on the EO-1 web site also contains the on and off times of the cryocooler. This may be used as a quick look tool.

2.3 Introduction to the Hyperion Spectra

Sample spectra from the San Francisco scene were extracted. Figure 8 indicates which region of the scene each spectrum represents. Figure 9 contains the spectrum for sample A, a rooftop. The spectrum is influenced by the solar radiance spectral profile (which resembles a black body of 6000K temperature with Fraunhoffer lines), modified by the reflection from the surface and atmospheric effects. Some atmospheric features are annotated in the Figure 9. The oxygen line, CO_2 and water absorption features are the most prominent. Also indicated in the Figure 9 is the overlap region of the VNIR and SWIR as well as the spectral channels that are not currently used.

Figure 10 displays additional spectral profile examples. Subtleties of the spectra and working with the spectra are described in chapter 4. For example while these spectra are illustrative of general trends, detailed analysis must include consideration of spectral smile, and spatial co-registration.

The wavelength included in the header file was used with the z-profile (spectrum) ENVI tool to create these plots. The spectrum was saved to an ascii file and then loaded into Excel. This process assigns the center wavelength included in the header to the spectrum. This wavelength is only accurate for the field-of-view pixel 128. Applications that want to take advantage of the spectral calibration need to use the SpectralL0_revA.dat file that is provided on the level 1 tape. This file contains the center wavelength for every single pixel. This is discussed more in a later chapter.

The spectral profiles presented in this section are a combination of the VNIR portion for one field of view location, and the SWIR portion for the corresponding field of view location. For applications in which the scene is highly variable spatially and when working with either .L1 or .L1_A data, attention must be paid to the VNIR-SWIR co-registration to make sure the combined spectrum truly represents the location of interest. L1_B data is spatially co-registered. The L1_A data was also returned to absolute radiance scale by dividing bands 1-70 in the VNIR by 40.0 and dividing the data in bands 71-242 by 80.0.

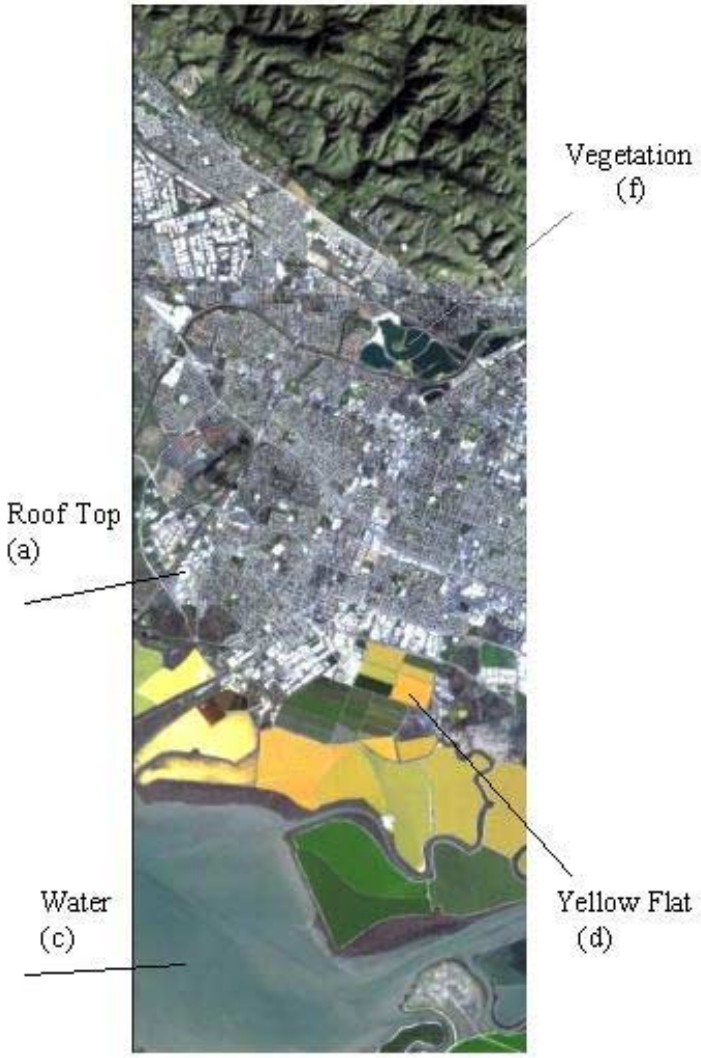

Figure 8: Locations of San Francisco Salt Ponds, 1-17-01 used for showing spectral examples

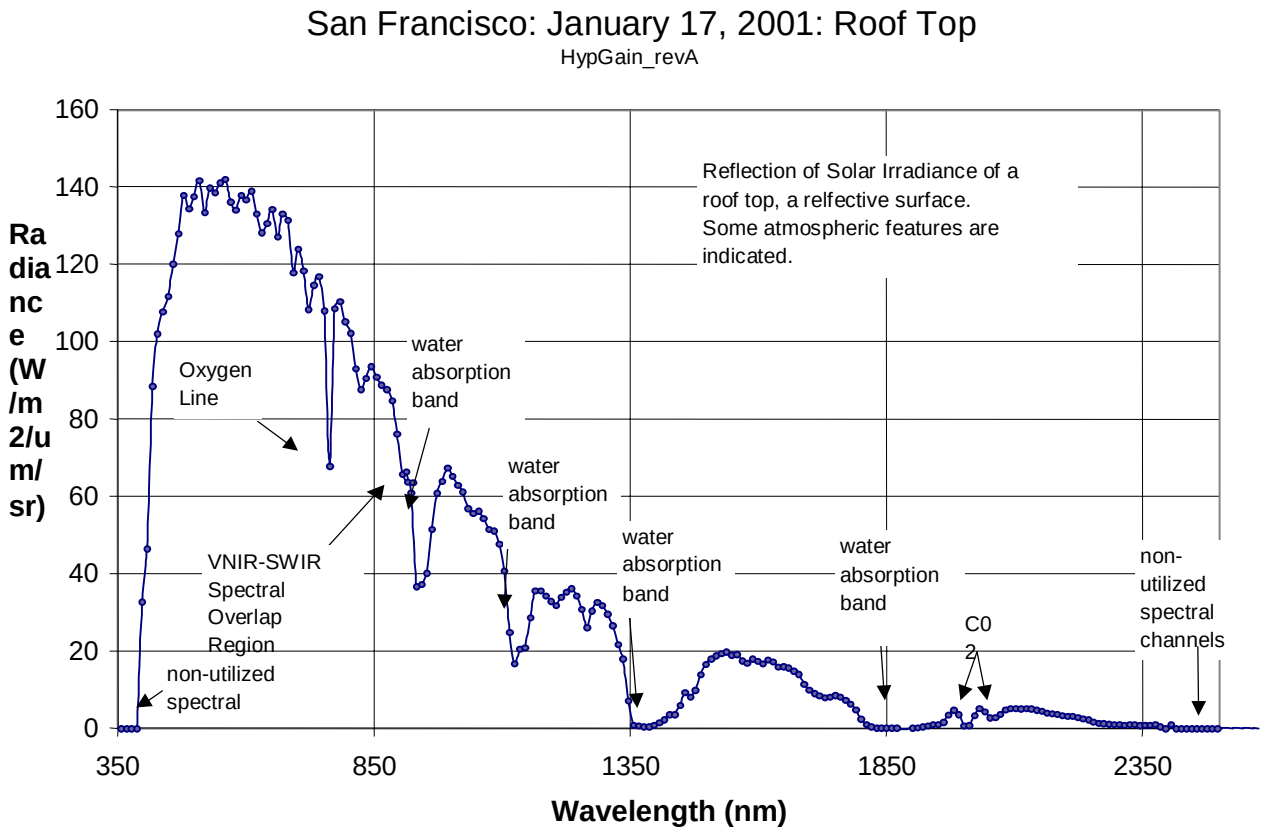

Figure 9: Example of a Hyperion Spectrum

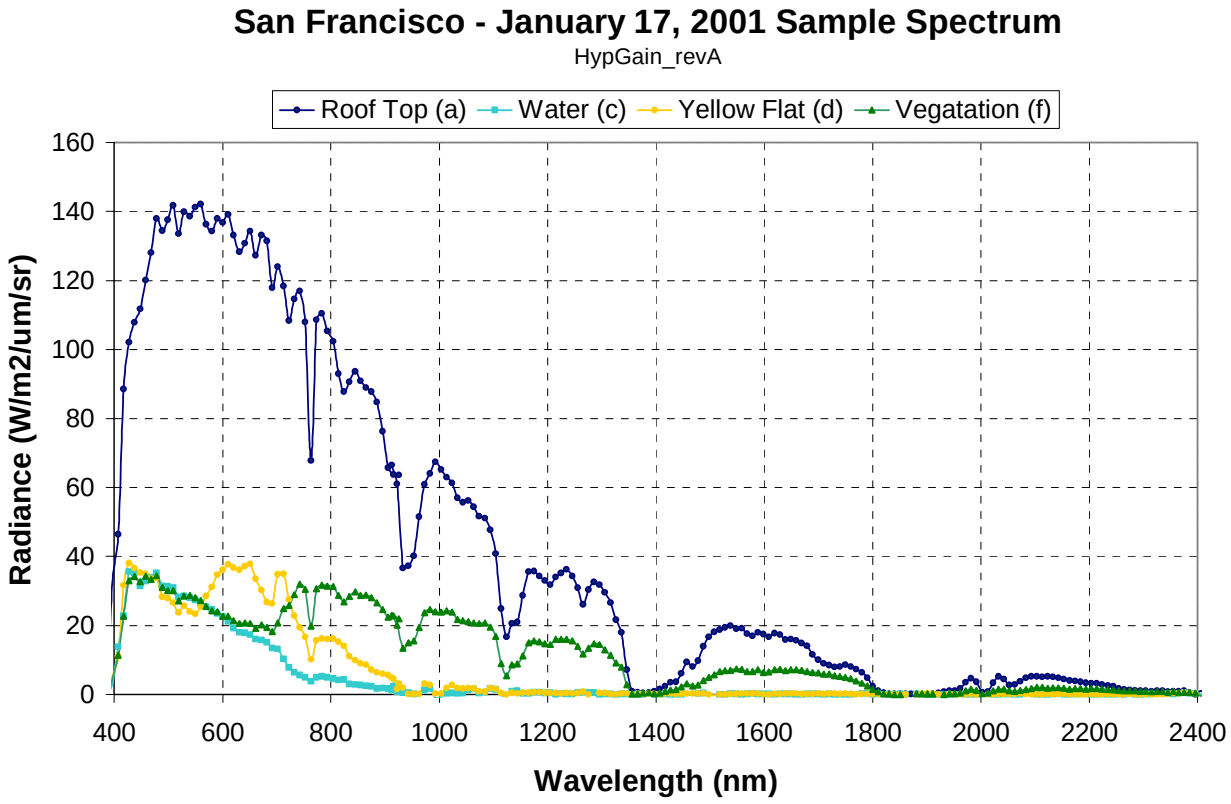

Figure 10: Additional examples of Hyperion Spectrum

2.4 Auxiliary Platform Notes -optional

This section is provided to help users not using ENVI get started. The user is responsible for proper incorporation into processing codes.

The Level 1 data format is dependent on the version of the processing code so there will be two formats. The original released Level 1 code data product, with data suffix .L1, was a 16 bit unsigned integer with units of radiance (W/m2/um/sr) times a factor of 100. The Level 1_A code, with data suffix .L1_A, data format is 16 bit signed integer, with units of radiance (W/m2/um/sr) times a factor of 40 for the VNIR (bands 1-70) and a factor of 80 for the SWIR (bands 71-242). The Level 1_B code has the same data format and units as Level 1_A, but the VNIR and SWIR data have been spatially co-registered.

For Matlab users the following lines are extremely useful. The first grouping can be used as a template for a code in which one frame at a time can be read-in. The second grouping is useful if a subset of the full image is exported. In this example, 330 lines of one spectral band were subset to a file. The data type would have to be changed for the updated level 1 products.

```
fid = fopen(fname, 'r')
npf = 242*256;
count = npf;
[tmp, count] = fread(fid, npf, 'int16');
img_tmp = reshape(tmp, 256, 242);
imagesc(img_tmp)
```

```
fid = fopen(fname, 'r');
npf = 330*256; count = npf;
[tmp, count] = fread(fid, npf, 'int16');
img_bnd = reshape(tmp,256,330);
imagesc(img_bnd')
```

For C programmers, here is an outline in code indicating how to get access to data in a HDF file. This is provided only in an attempt to assist users in accessing the data directly.

```
.
int sd_id = SDstart(hdf_file, DFACC_READ);
        < == Open a HDF file to get an ID

SDfileinfo(sd_id, &nDataSets, &nFileAttrs);
        < == General info: nDataSets -- no. of data sets; nFileAttrs -- no. of attributes
.
.       /* prepare to get access to the data sets */
.
/*  Retrieve data sets */
for(int index = 0; index<nDataSets; index++)
{
        int sds_id = SDselect(sd_id, index);
                < == Get an ID for the data set given by an integer of  "index"

        SDgetinfo(sds_id, name, &rank, dim, &data_type, &n_attrs);
                < ==  Get general info of the data set
.
.       /* use the info to set up proper parameters to get access the data set */
.
        SDreaddata(sds_id, start, NULL, edge, (VOIDP)(buff)) ;
                < == Read the data set and store the data in buff
.
.       /* data processing */
.
        SDendaccess (sds_id);
                < == Close the data set
}
.
.       /* further data processing */
.
SDend(sd_id);
        < == After the processing, close the HDF file
```

3 HYPERION DATA COLLECTION, FLOW AND PROCESSING

This chapter describes the data collection event sequence, the data flow and level 0 and level 1 processing steps. The data collection event sequence and timeline is presented with a sample level 0 filename set. The types of data collection events are described for users who rely on non-ground images. The flow of the data, from the user request to the shipment of the data to the user is highlighted. Then the details of the level 0 and level 1 processing are discussed. For the level 1

processing discussion, the steps as well as the data files that are created at each step of the data processing sequence are presented with sample metadata files described as examples.

3.1 Hyperion Data Collection Event Sequence

The basic Hyperion Data Collection Event (DCE) consists of three dark collects, the scene and a lamp collect. A sample timing of the sequence and the naming of each collection are provided in Table 4 below. The times are presented in terms of mm:ss (minutes:seconds) relative to the specified scene collection time. For example, the instrument is placed in Standby mode, 10 minutes 31 seconds before the start of the image collection. The instrument is placed in Idle mode, 4 minutes after the end of the image collection. Although this format may seem unnatural, it is the form the EO-1 planners use in scheduling Hyperion collects and is used here for consistency. Hyperion collects data at a frame rate of 223.4Hz. The dark collection is 1 second (~220 frames), the image is typically ~30 sec (~6925 frames) and the lamp collect is 3 seconds (~660 frames).

The output filename is in this format: EO1yyyyddd_vvvvssss_r1_ggg_XX_.L0. This format is described in section 3.4.2

Table 4: Basic Data Collection Event Timeline

Event	Mm:ss (relative to scene start)	Product	Example L0 name Ex: LakeFromeDay005Year2001
Standby	-10:31		
Dark collect start	-00:31	Dark # 1 (Pre-Image Dark)	EO12001005_122A1229_r1_PF1_01.L0
Dark collect stop	-00:30		
Cover open	-00:28		
Image start	-00:03	Scene	EO12001005_122D122C_r1_PF1_01.L0
(Variable length image)	00:00		
Image stop	+00:03		
Cover closed	+00:11		
Dark collect start	+00:29	Dark # 2 (Post- Image Dark)	EO12001005_122F122E_r1_PF1_01.L0
Dark collect stop	+00:30		
Lamp on	+00:32		
Lamp collect start	+03:32	Lamp Collect	EO12001005_12371236_r1_PF1_01.L0
Lamp collect stop	+03:35		
Lamp off	+03:37		
Dark collect start	+03:57	Dark # 3 (Post-Lamp Dark)	EO12001005_12341233_r1_PF1_01.L0
Dark collect stop	+03:58		
Idle	+04:00		

3.2 Types of Hyperion Data Collection Events

Although there is one standard DCE sequence, there are subtleties in the details of the collection, Table 5. For example the standard ground image collect is 30 seconds with the center 24 seconds being the primary region of interest. The solar calibration DCE is nominally 16 seconds.

In addition to the length of each image, there are subtleties in the spacecraft pointing and motion during the collect. For the ground collect, the spacecraft pitch/yaw is commanded so Hyperion views the ground directly. For a solar calibration or atmospheric limb collect, the spacecraft pitch/yaw is modified so that Hyperion views the reflection off the diffuse surface on the inside of the cover. In both cases the pointing direction is commanded prior to the scene such that the spacecraft motion has settled prior to the start of the collect. For a lunar, stellar or planetary collect, the spacecraft motion is commanded throughout the collect, which results in a scan.

Table 5: Types of Data Collection Events

scene	Atmosphere effects	Collect (sec)	Spacecraft Motion	View
Ground	Yes	30	Point	Direct
Lunar Stellar Planetary	No	varies	Scan	Direct
Solar	No	16	Point	Diffuse Reflection
Atmospheric Limb	Yes	16	Point	Diffuse Reflection

3.3 Data Flow from the Spacecraft to the User

There are a few steps that have to occur in order for the user to obtain Hyperion data for a specific scene. For example, the user must submit a request to GSFC that of a desired site should be collected. The user would supply the latitude and longitude of the site, as well as the date of the collect if it were critical. The user should also provide any other additional information that may be important to the planners. For example day/night collect, take no matter what, take only if no clouds, ground truth coincident is some factors that would be worthwhile to relay to the planners. The scene would then be scheduled consistent with existing priorities.

The spacecraft would collect the scene. The Hyperion science data and ancillary data obtained during the DCE would be stored on the WARP. The Hyperion science data includes the five data files described above and the ancillary data refers to the instrument telemetry obtained during the DCE. The WARP also stores science data from the other instruments as well as ancillary data from the other instruments and select subsystems. The science data and ancillary data are downlinked to one of several ground stations using an X-band downlink. All of this data is recorded on Ampex tape and sent to GSFC by the ground stations.

GSFC performs Level 0 processing on the data. Description of this processing is provided in the next section. GSFC sends the Level 0 data and ancillary data, on a DLT to TRW and indicates which scenes should be processed to Level 1. GSFC also sends the Level 0 data to the user before the Level 1 data has been produced.

TRW performs Level 1 processing on requested DCEs. Level 1 processing produces metadata files, which can be used to track the processing steps as well as give an indication on the quality of

the Level 1 data product. TRW sends the Level 1 data and the metadata files to GSFC on a DLT. GSFC distributes data to the user.

Nominally it takes GSFC 3-5 days from receipt of the raw data to perform Level 0 processing and deliver the tapes to TRW. TRW performs Level 1 processing and ships the final Level 1 data product with metadata files for select DCEs to GSFC within 3 days of receipt of the Level 0 data. GSFC will then forward the Level 1 data to the people who request the scene.

It is possible for the user to receive a tape from GSFC that contains the Level 0 Hyperion data and then later receive a tape that contains the Hyperion Level 1 data. The Level 0 should not be used for science applications because artifact corrections have not been performed.

The following is a highlight of the process of the Hyperion data flow described above.

1.) Scene request submitted
2.) Scene scheduled
3.) Scene collected and stored on WARP
4.) Scene downloaded to a ground station
5.) Ground Station sends data to GSFC
6.) GSFC performs Level 0 processing
7.) GSFC sends Level 0 data to TRW on a DLT (and sends Level 0 data to the requestor)
8.) TRW performs Level 1 processing on requested scenes
9.) TRW sends Level 1 data to GSFC on a DLT
10.) GSFC sends Level 1 data sets to the requestor

3.4 Description of the Hyperion Level 0 Data Processing

Level 0 processing of EO-1 Hyperion science data refers to the following set of tasks that are performed on data that has been downlinked from the spacecraft. The processing turns the downlinked data into a set of Level 0 files with prescribed file names. The Level 0 processing does not include artifact correction. The SWIR smear and echo artifact correction is required for all science applications. The absolute calibration is not valid unless the smear and echo corrections have been performed and the level 0 data set has been properly processed.

The Level 0 output file also includes HDF attributes. The HDF attributes include Scientific Data Set (SDS) attributes. The subsequent sections discuss the Level 0 processing steps, the ancillary HDF data files and the SDS attributes.

3.4.1 Hyperion Level 0 Processing

Level 0 processing of EO-1 Hyperion science data refers to the following set of tasks that are performed on data that has been downlinked from the spacecraft. This set of tasks is performed by GSFC on all scenes that are collected. A .L0 extension indicates that Level 0 processing has occurred. The details are provided for those who require this level of detail. For most users, the most important thing to note is that Level 0 processing does not perform artifact correction on the SWIR data. The corrections are required for absolute radiometric accuracy.

1) *Decode the data:* Perform Reed-Solomon decoding on downlinked science data. Extract the science data from the telemetry data and flag corrupted data;
2) *Separate the data into files:* Separate according to data type boundaries, DCE image number boundaries, and data stream boundaries. Lunar calibration, ground image, solar calibrations are

examples of data type boundaries. Pre-image dark, image, post-image dark, are examples of data stream boundaries.

3) *Perform checks to verify data integrity and instrument performance*: If a check fails, then the program terminates with a descriptive error message.

4) *Combine the VNIR and SWIR data sets:* Arrange VNIR-SWIR pixel order. Confirm that the VNIR and SWIR file pair-up properly. Verify that the two filenames have the same year and day stamp, represent the same DCE image number; same event type, and same data type (i.e., pre-image dark cal, image, post-image dark cal, or lamp cal); Concatenate the VNIR and SWIR science data together.

5) *Create HDF:* Send the science data into a formatted output file (HDF format). Append "HDF attributes" to the output file. These attributes, which are described below in detail, list various properties about the data.

3.4.2 Hyperion Level 0 Output File Naming Convention

The Level 0 processing output for Hyperion consists of a set of five files with the .L0 extension for each DCE. Data in this output file is referred to as Hyperion "Level 0" data.

The output filename is in this format: EO1yyyyddd_vvvvssss_r1_ggg_XX_.L0, for example, EO12001005_122A1229_r1_PF1_01.L0 is the pre-image dark taken January 5th 2001. The yyyyddd date is the UTC or Julian date of the beginning of the DCE collection where yyyy is the year and ddd is the day of year with January 1 corresponding to 001. The next section, vvvv and ssss are the hex representations of the two-byte VNIR and SWIR file IDs. This is used to identify the instrument, the focal plane, the image number, and the type of collect. The decoding of the hex representation is a complex process and is out of scope for this document. The information contained in the hex representations is already "decoded" for the user and is contained in the SDS attributes provide below. "r1" indicates this is the first run of this data set through the data processing software. ggg is an identifier indicating from which ground station the data were received. XX represents the number of downlink attempts for ground station "ggg".

3.4.3 Ancillary HDF Data Files

Included on a DLT with the level 0 Hyperion data are a set of HDF files referred to as "ancillary data", as introduced above. The ancillary data are a subset of spacecraft and instrument telemetry recorded during the related DCE. The list of Hyperion mnemonics included in the ancillary data is presented in Table 6 along with a brief description and typical values. The Hyperion HDF file names follow the format, yyyy_ddd_hyp.hdf, indicating the year (yyyy) and Julian date (ddd) of the data, which has been recorded for all the DCEs taken on that date. The telemetry values are recorded in engineering units, where applicable. The values for the mnemonics are reported in the ancillary data along with the corresponding Mission Elapsed Time (MET) in seconds. The MET is also recorded with the image date. To convert to Greenwich Mean Time, the Universal Time Correlation Factor (567,648,000 sec) must be added to the MET.

Table 6: Hyperion Mnemonics included in the Ancillary Data

Mnemonic	Description (typical values)
YIMAGE_MODE	Image mode (idle, standby, imaging)
YCOVRSTAT	Commanded cover position status (0=closed, 1=solar cal position, 2=open)
YLAMP1VAL	Calibration lamp 1 commanded value (0)

Mnemonic	Description (typical values)
YLAMP2VAL	Calibration lamp 2 commanded value (0-255)
YLAMP1CUR YLAMP2CUR	Hyperion lamp currents (~0.98A when on, note: YLAMP1CUR is always ~0)
YLAMP1VOL YLAMP2VOL	Hyperion lamp voltages (~7.4V when on, note: YLAMP1VOL is invalid))
YHSATEMP5	VNIR ASP temperature (32-34C)
YHSATEMP6	SWIR ASP temperature (~4-5C)
YCOVERPOS	Hyperion cover position (counts, 3424=closed, 3212=solar cal, 2678=full open)
YSWIRFPET	Hyperion SWIR FPE temperature (-153.5 $\pm$ 1C when at proper operational temperature)
YVNIRFPET	Hyperion VNIR FPE temperature (2-10C)
YHEAP5V	Hyperion HEA +5 volts (~4.8V)
YHEAP15V	Hyperion HEA +15 volts (~14.99V)
YHEAN15V	Hyperion HEA -15 volts (~ -14.9V)
YVNIRP5VD	Hyperion VNIR +5VD (~5.22V)
YVNIRP5VA	Hyperion VNIR +5VA (~5.02V)
YVNIRM5VA	Hyperion VNIR -5VA (~ -4.94V)
YVNIRP15VA	Hyperion VNIR +15VA (~14.98V)
YVNIRM15VA	Hyperion VNIR -15VA (~ -14.92V)
YSWIRP5VD	Hyperion SWIR +5VD (~4.99V)
YSWIRP5VA	Hyperion SWIR +5VA (~5.03V)
YSWIRM5VA	Hyperion SWIR -5VA (~ -4.95V)
YSWIRP15V	Hyperion SWIR +15 Volts (~14.99V)
YSWIRM15V	Hyperion SWIR –15 Volts (~ -14.9V)
YCLAMP12VOL	Cal lamp power supply voltage (~13.0 when on)
YCOMCTR	Hyperion command counter (variable)
YERRCTR	Hyperion error counter (variable)
YCOLDHEADTEMP	Cryocooler coldhead temperature (~110K, when cryocooler is operating)
YOUTDBRSS	Cryocooler 10 Log10 (RSS of all harmonics)
YMOTORDRIVE	Cryocooler motor drive (75-89% when cryocooler is operating)

3.4.4 Explanation of SDS Attributes in Level 0 product

The SDS attributes for the Hyperion Level 0 data files are listed in Table 7. A description of each of the attributes follows. The values in the example represent a pre-image dark collect. This level of detail is provided for the advanced user.

Table 7: SDS Attributes for Hyperion Level 0 Data

NAME	Max. Length	HDF Type	Example Value
Image Attribute	256	8-bit character	*"Pre-image dark"*
Level 0 File Generated By	256	8-bit character	"HLZP version 1.0.0"
Byte Order	256	8-bit character	"big"

NAME	Max. Length	HDF Type	Example Value
Level 0 File Generated At	14	8-bit character	"yyyy_ddd_hhmmss"
Frame Numbers	2	32-bit unsigned integer	0-222
Dimensions: Number of Cross Track Pixels	1	16-bit integer	256
Number of Bands	1	32-bit integer	242
Number of Frames	1	32-bit integer	223
Pixel Order	8	Bit character	"BIL"
Number of Missing Pixels	1	32-bit unsigned integer	0
VNIR Sync Time [beginFrame,endFrame,syncTime]	3N	32-bit integer	0-176 39 177-222 121
SWIR Sync Time [beginFrame,endFrame,syncTime]	3N	32-bit integer	0-176 39 177-222 121
VNIR Time Code [beginFrame, endFrame,TC3,TC4,TC5,TC6, TC7,TC8]	8M	32-bit integer	0-177 143 0 224 204 214 5 178-222 143 0 225 204 214 5
SWIR Time Code [beginFrame, endFrame,TC3,TC4,TC5,TC6, TC7,TC8]	8M	32-bit integer	0-177 143 0 224 204 214 5 178-222 143 0 225 204 214 5
VNIR Channel Offset [A,B,C,D]	4	8-bit unsigned integer	8,8,8,8
SWIR Channel Offset [A,B,C,D]	4	8-bit unsigned integer	97,97,104,102
SWIR Gain Setting [A,B,C,D]	4	8-bit unsigned integer	1,1,1,1
SWIR Integration Time Setting	1	8-bit unsigned integer	125

Image attribute This attribute describes what type of data is contained in the data file, e.g., pre -image dark cal, image, post-image dark cal, lamp cal, post-lamp dark cal.

Level 0 File Generated By This attribute defines which version of the level 0 processing code was used to process the data file, e.g., HLZP version 1.0.0.

Byte Order This attribute indicates that the file byte order is "big endian" rather than "little endian". Different hardware/software combinations assume different byte orders. For example, PCs, SGI Windows, SGI LINUX and Dec Alpha UNIX use "little endian" byte order while SGI IRIX and Sun UNIX use "big endian". ENVI is compatible with either and reads this attribute.

Level 0 File Generated At	provides the time at which the level 0 processing was performed in year (yyyy), Julian day (ddd), and GMT (hhmmss).
Frame Numbers	provides the number of the start and stop frame for the file. The start frame number is 0. For a nominal DCE image collect, the end frame number would be ~6925. For a dark file, the end frame number would be ~223.
Dimensions	are given as the number of cross-track pixels x number of spectral bands x number of frames (along-track pixels)
Number of Cross Track Pixels	The number of cross track or field-of-view (FOV) pixels is fixed at 256. This number will not vary.
Number of Bands	The number of bands is the same as the number of spectral channels, which is 242 and does not vary. Some images may not have valid SWIR data (if the SWIR focal plane was not held at its operational temperature during the imaging event), but there will still be 242 spectral bands in each data file.
Number of Along Track Pixels	The number of along-track pixels will mirror the frame number range, will vary depending on file type (e.g., dark, image) and may vary from image to image. The number of along-track pixels will be the same as the number of frames of data. The frame rate is 223.4 frames/sec. A nominal ground image is 30 seconds long, a dark file is 1 sec long, and a lamp file is 3 seconds long. The length of the ground image may vary.
Pixel Order	The pixel order for all files is BIL, Band Interleaved by Line
Number of Missing Pixels	Level 0 processing detects and flags pixels with missing data. This attribute informs the user of how many pixels were found to have missing data, although it does not identify which pixels were affected.
VNIR Sync Time [beginFrame,endFrame,syncTime]	The sync time is the time from the spacecraft Time Code pulse to the Hyperion frame sync pulse with 32 μsec resolution. The values of the attribute show the beginning and ending frames (e.g., 0-176) and the value of the sync time (e.g., 39).
SWIR Sync Time [beginFrame,endFrame,syncTime]	See previous attribute. The VNIR and SWIR receive their Time Codes and Sync Times separately.
VNIR Time Code [beginFrame,endFrame,TC3,TC4,TC5,TC	The Time Code is the time broadcast by the spacecraft to Hyperion and is updated every second (± 2 msec). The Time Code information included here shows the beginning frame of the file,

6,TC7,TC8]	the end frame of the file and the value of the time code that was received at the beginning frame. The Time Code is constant over the range of frames included between the "beginFrame" and "endFrame". The values of the attribute show the beginning and ending frames (e.g., 0-177) and the value of the time code from least to most significant number. The time code values (TC3-8) are decimal representations of hexadecimal numbers that reflect the UTC time. TC5-8 are time codes values in seconds, TC3 and 4 are sub-seconds.
SWIR Time Code [beginFrame,endFrame,TC3,TC4,TC5,TC6,TC7,TC8]	See previous attribute. The Time Code values for corresponding SWIR and VNIR frames should be the same.
VNIR Channel Offset [A,B,C,D]	This attribute provides the VNIR offset settings, which are fixed for the course of the EO-1 mission.
SWIR Channel Offset [A,B,C,D]	This attribute provides the SWIR offset settings, which are fixed for the course of the EO-1 mission.
SWIR Gain Setting [A,B,C,D]	This attribute provides the SWIR gain settings, which are fixed for the course of the EO-1 mission.
SWIR Integration Time Setting	This attribute provides the SWIR integration time setting, which is fixed for the course of the EO-1 mission.

The SDS attributes generated during the level 0 processing are carried over and appear with the level 1 files, as well.

3.5 Description of the Hyperion Level 1 Data Processing

3.5.1 Hyperion Level 1 Processing

The Hyperion level 1 processing refers to the processing performed by TRW to produce the radiometric calibrated Hyperion science data. Hyperion "level 1 processing" applies to processing performed using the Level 1 code, Level 1_A, and Level 1_B code. Processing with the Level 1_A code began July 1, 2001. Processing with the Level 1_B code began November 15, 2001. The four revisions in the Level 1_A code include:

1. Instead of subtracting the dark file nearest to the image, an interpolated dark file is calculated using the dark files collected pre-and post-image and subtracted from the image
2. Output of the level 1_A code is a signed integer rather than an unsigned integer, as in level 1
3. Level 1 output was in units of (watts/(sr-micron-m^2))x100. Because of the change listed in (2) above, the multiplication factor was revised so that VNIR is in units of (watts/(sr-micron-m^2))x40 and SWIR is in units of (watts/(sr-micron-m^2))x80. This change allows retention of maximum precision without overflowing the size limit for 16-bit signed integer output.
4. In the unusual event that pixels are saturated in the SWIR, the smear and echo corrections become invalid. This has been observed in only a few scenes out of the 1400 collected to date

and are typically gas plumes or volcanic hot spots. Because saturation affects the validity of the data in subtle ways, the Level 1_A code first scans the level 0 data for saturated pixels and produces a log file, .sat, to identify saturated pixels as well as those pixels whose value is suspect because of invalid echo and smear corrections.

Timed with the release of the Level 1_A code was a release of an improved calibration file and improved echo correction file.

There was one significant revision associated with the Level 1_B code. Level 1_B follows the same processing steps as Level 1_A but, in addition, Level 1_B spatially co-registers the VNIR and SWIR data. In addition, the Level 1_A log file, .sat, that reports on saturated pixels in the level 0 data was modified to indicate the location of the pixels in the Level 1_B data because the co-registration process shifts the SWIR pixel locations. Finally, the Level 1_A dark interpolation process was modified slightly to account for the full duration of time between the pre-image dark file and the start of the image (~30 seconds).

GSFC sends the Level 0 processing data to TRW along with a request list of scenes to be processed to Level 1. TRW performs the Level 1 processing. A flow chart for the Hyperion Level 1 processing using the original Level 1 code is shown in Figure 11. A flow chart for the updated Hyperion Level 1_ A and Level 1_B processing is shown in Figure 12. The charts are broken into data processing steps and indicate the function that is performed and the metadata file that is created to track the processing steps. Ground image, solar calibration and lunar calibration data are processed identically.

The first step, in both the Level 1_A and Level 1_B processing codes, is to identify saturated pixels. The first step in the originally released Level 1 processing code was to correct for image artifacts. This is the second step in the Level 1_A and Level 1_B codes. There are two artifacts in the SWIR, echo and smear. Because the corrections for echo and smear depend on signal level, corrections based on a saturated signal level are invalid. Level 1_A produces a metadata file (MD15) that reports all saturated pixels as well as those pixels whose derived smear and echo corrections will be invalid. MD15 is slightly different in the Level 1_B code in that it reports the location of saturated pixels before (.L0) and after co-registration (.L1_B). Following the flagging step in Level 1_A and Level 1_B codes, all Level 0 SWIR data (image and dark) are corrected for smear and echo artifacts.

The next step is to subtract off a dark frame. This is required because each image includes not only the scene signal but also a signal caused by thermally generated electrons in the bulk material. To enable removal of this signal from the image, a pre-image and a post-image dark frame are taken as part of each DCE. Each dark file is 1 second of data, corresponding to approximately 220 frames. The original Level 1 processing code performed the dark subtraction using the averaged dark file that was obtained closest in time with the image. The Level 1_A and Level 1_B processing codes use a dark value that is interpolated in time between the pre-image dark and post-image dark, although the Level 1_B code includes the full wait time, between the pre-image dark collect and the start of the image, when performing dark interpolation calculations.

A calibration file, HypGain, is applied to radiometrically correct the images. An improved calibration file was released at the same time as the release of the Level 1_A code. HypGain was used by the Level 1 code and HypGain_revA was used by the Level 1_A code. For the current revision status of the HypGain file and as brief summary of changes, please refer to the

"L1readme_r3" file found in Appendix 1. The HypGain file is used for all Hyperion scenes. This file is described in more detail in chapter 4. Pixels that are known to be dead are replaced with an average of neighboring field-of-view (FOV) pixels or with 100% of the neighboring pixel if on the edge of the FOV prior to generating the Level 1 data file. The bad-pixel list was defined pre-flight. A few bad pixels have been added since the pre-flight list was generated. These pixels are listed in Appendix 1. Some of the pixels on the bad-pixel list are in the portion of the focal plane, which is not calibrated. The remaining pixels that are corrected for the user are listed below and presented in terms of Spectral Channel (Band) / field-of-view location (FOV)
SWIR = 200/8, 201/8, 169/23, 99/92, 94/93, 190/113, 203/115, 116/138, 165/148, 119/240, 120/240, 168/256
VNIR = 1-35 / 1

Spatial co-registration of the VNIR and SWIR data is the last step in Level 1_B data processing. SWIR data are shifted into alignment with the VNIR pixels (see Figure 11). In the cross-track (field of view, FOV) dimension (X), the SWIR pixels are shifted by -1. FOV pixel #1 is removed (1) and pixel #256 is padded with zeros (2). In the along-track dimension (Y), FOV pixels 129-256 are shifted by +1 pixel. For frame 1, FOV pixels 129-256 are padded with zeros (3) and the last frame is removed (4). A metadata file – EO1YYYYDDD_VVVVSSSS_r1_XXX.aln.log is generated to show that co-alignment has been performed on the level 1 data product. The Level 1_B saturated pixel report (EO1YYYYDDD_VVVVSSSS_r1_XXX.sat) contains the location of both L0 and L1_B saturated pixels (the co-alignment process changes the locations of SWIR pixels).

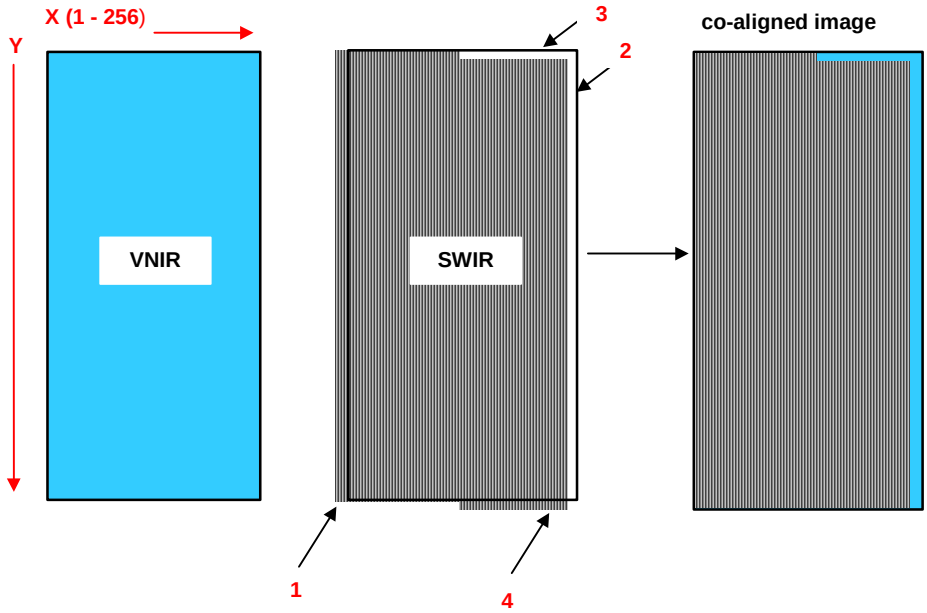

Figure 11 VNIR-SWIR Spatial Co-registration

The Level 1 data set consists of radiometrically-corrected images formatted as HDF files, and metadata in binary and ASCII formats. The data format and units for the data files have changed as the level 1 processing has been modified. For data processed using the Level 1 code, the data type is 16-bit unsigned integer and the units are (watts/(sr-micron-m^2)x100). For data processed using the Level 1_A or Level 1_B code, data type is a 16-bit signed integer with units of ((watts/(sr-

micron-m^2)) x40), for VNIR data and ((watts/(sr-micron-m^2)) x80), for SWIR data. Both the file extension and the header can be used to determine the version of the level 1 processing code.

Table 8 defines all Level 1, Level 1_A, and Level 1_B data products. Level 1 metadata filenames have an extension attached that indicates the intermediate Level 1 process (e.g., after smear correction, echo correction, dark subtraction) from which the file was generated, although the intermediate files are not included on the tape. The metadata file ID number is provided for historical reference and is not required for the user. However it is the number referenced in the flow diagrams presented in figures 12 and 13.

The .L1 appendage is reserved for the final, fully processed radiometric calibrated output of the Level 1 code. The .L1_A appendage is reserved for the final, fully processed radiometric calibrated output of the Level 1_A code. The .L1_B appendage indicates the final, fully processed radiometric calibrated and spatially co-registered output of the Level 1_B code. The "_rX" in the file name is a revision number that allows differentiating files that have been processed more than once for some reason (e.g., revised calibration file or subsetting for a specific application). The file with the .L1.hdr, .L1_A.hdr, or .L1_B.hdr appendage is an ENVI-ready header for linking the band number with the band center wavelength. The center wavelength for field-of-view 128 is supplied for this header file. This header file should be used with caution. It is a useful tool for quick looks, but the full spectral calibration file, SpectralL0_revA should be used for any detailed analysis.

Log files generated during Level 1 processing provide a record of the intermediate processing steps. The log files associated with the intermediate files retain the image filename followed by .log. The purpose of the log files is to indicate that the intermediate processing has occurred and, in some cases indicate details of the processing that occurred. Figures 12 and 13 shows which metadata files (MD#) are produced during intermediate processing steps. Selected metadata files are presented in the following section as examples.

In addition to the processing steps, an image quality assessment is performed as a qualitative spot check on a single cube parsed from a requested DCE. The results are reported in metadata file #11 (MD11). The form is discussed in the next section.

Figure 12: Level 1 Data Processing Flow Diagram

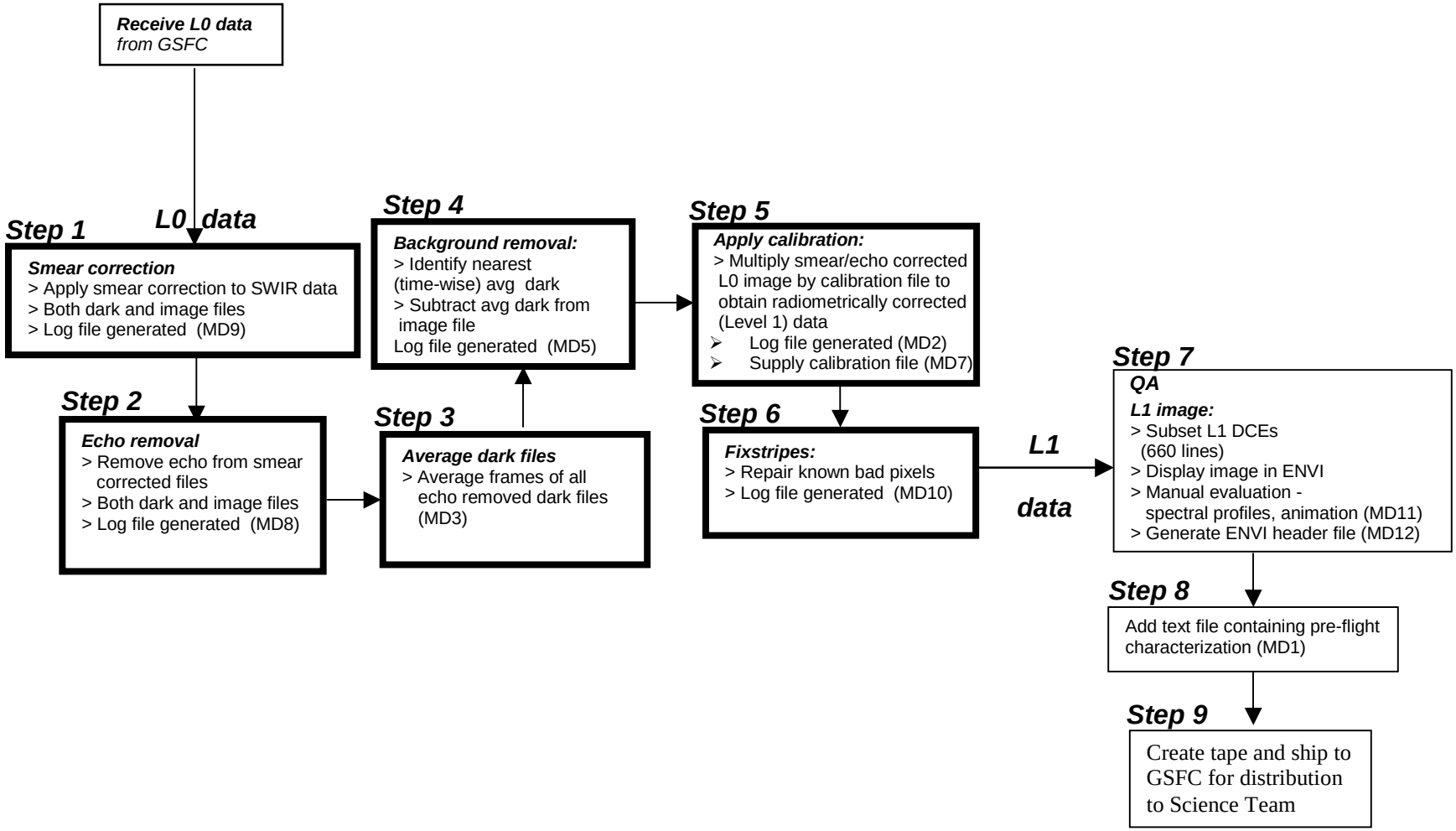
Receive L0 data
from GSFC
L0 data
Step 1
Smear correction
> Apply smear correction to SWIR data
> Both dark and image files
> Log file generated (MD9)
Step 2
Echo removal
> Remove echo from smear corrected files
> Both dark and image files
> Log file generated (MD8)
Step 3
Average dark files
> Average frames of all echo removed dark files (MD3)
Step 4
Background removal:
> Identify nearest (time-wise) avg dark
> Subtract avg dark from image file
Log file generated (MD5)
Step 5
Apply calibration:
> Multiply smear/echo corrected L0 image by calibration file to obtain radiometrically corrected (Level 1) data
Log file generated (MD2)
Supply calibration file (MD7)
Step 6
Fixstripes:
> Repair known bad pixels
> Log file generated (MD10)
L1 data
Step 7
QA
L1 image:
> Subset L1 DCEs (660 lines)
> Display image in ENVI
> Manual evaluation - spectral profiles, animation (MD11)
> Generate ENVI header file (MD12)
Step 8
Add text file containing pre-flight characterization (MD1)
Step 9
Create tape and ship to GSFC for distribution to Science Team

Figure 13: Level 1_A Data Processing Flow Diagram

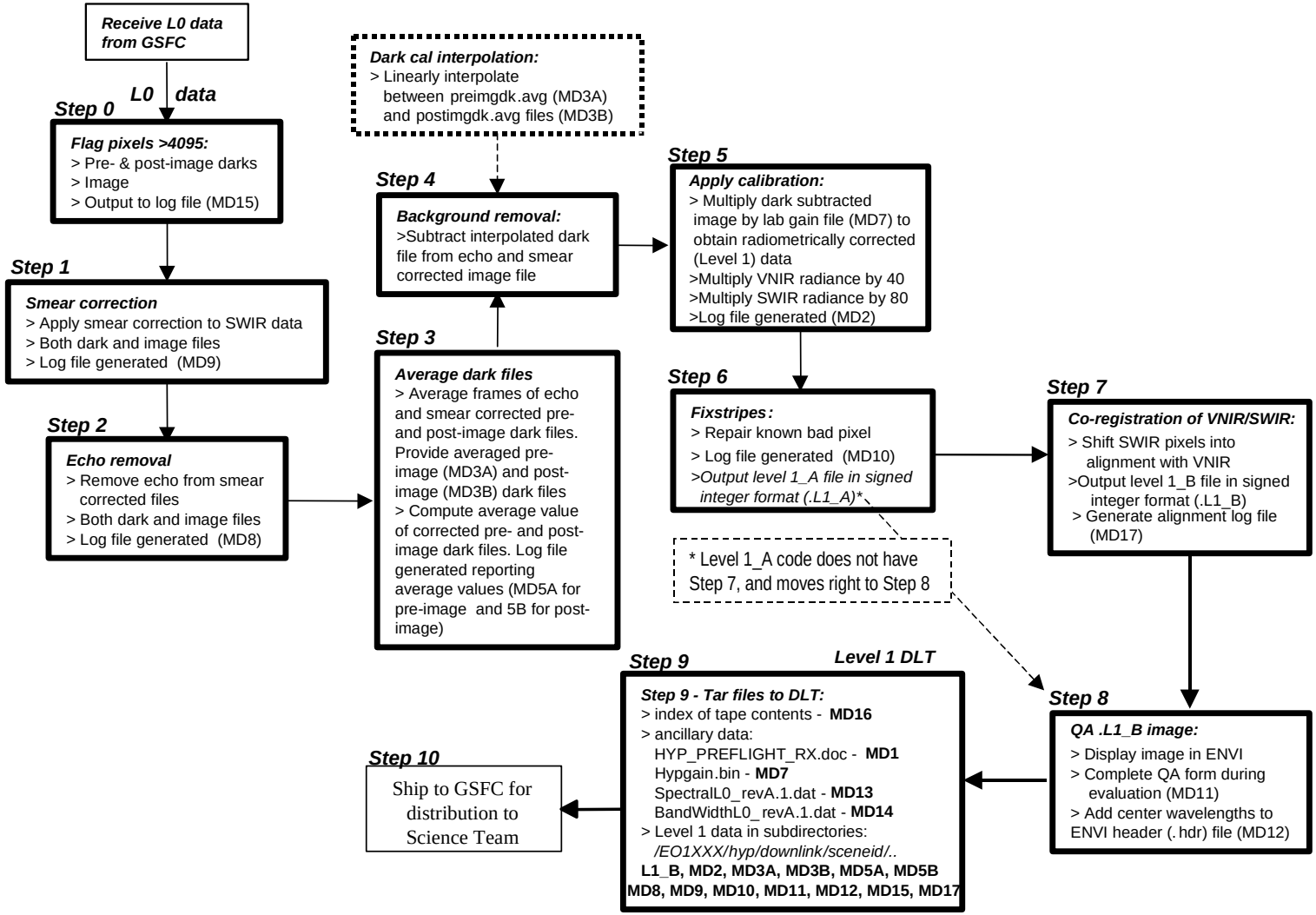
Receive L0 data from GSFC
L0 data
Step 0
Flag pixels >4095:
> Pre- & post-image darks
> Image
> Output to log file (MD15)
Step 1
Smear correction
> Apply smear correction to SWIR data
> Both dark and image files
> Log file generated (MD9)
Step 2
Echo removal
> Remove echo from smear corrected files
> Both dark and image files
> Log file generated (MD8)
Dark cal interpolation:
> Linearly interpolate between preimgdk.avg (MD3A) and postimgdk.avg files (MD3B)
Step 4
Background removal:
>Subtract interpolated dark file from echo and smear corrected image file
Step 3
Average dark files
> Average frames of echo and smear corrected pre- and post-image dark files. Provide averaged pre-image (MD3A) and post-image (MD3B) dark files
> Compute average value of corrected pre- and post-image dark files. Log file generated reporting average values (MD5A for pre-image and 5B for post-image)
Step 5
Apply calibration:
> Multiply dark subtracted image by lab gain file (MD7) to obtain radiometrically corrected (Level 1) data
>Multiply VNIR radiance by 40
>Multiply SWIR radiance by 80
>Log file generated (MD2)
Step 6
Fixstripes:
> Repair known bad pixel
> Log file generated (MD10)
>Output level 1_A file in signed integer format (.L1_A)*
* Level 1_A code does not have Step 7, and moves right to Step 8
Step 7
Co-registration of VNIR/SWIR:
> Shift SWIR pixels into alignment with VNIR
>Output level 1_B file in signed integer format (.L1_B)
> Generate alignment log file (MD17)
Step 8
QA .L1_B image:
> Display image in ENVI
> Complete QA form during evaluation (MD11)
> Add center wavelengths to ENVI header (.hdr) file (MD12)
Step 9
Level 1 DLT
Step 9 - Tar files to DLT:
> index of tape contents - MD16
> ancillary data:
HYP_PREFLIGHT_RX.doc - MD1
Hypgain.bin - MD7
SpectralL0_revA.1.dat - MD13
BandWidthL0_ revA.1.dat - MD14
> Level 1 data in subdirectories:
/EO1XXX/hyp/downlink/sceneid/..
L1_B, MD2, MD3A, MD3B, MD5A, MD5B
MD8, MD9, MD10, MD11, MD12, MD15, MD17
Step 10
Ship to GSFC for distribution to Science Team

Table 8: Hyperion Level 1 Data Set

L1 = processed data using Level 1 code
L1_A = processed data using the Level 1_A code
L1_B = processed data using the Level 1_B code
MD# = Metadata file number #

Output (ref. only)	**Step in Process**	**File Name**	**Data File Description and Format**
L1	Completion of Step 6	EO1YYYYDDD_VVVVSSSS_rX.L1	Fully processed Level 1 DCE (Data Collection Event) HDF, band interleaved by line (BIL) order
L1_A	Completion of Step 6	EO1YYYYDDD_VVVVSSSS_rX.L1_A	Fully processed Level 1 DCE (Data Collection Event) HDF, band interleaved by line (BIL) order
L1_B	Completion of Step 7	EO1YYYYDDD_VVVVSSSS_rX.L1_B	Fully processed Level 1 DCE (Data Collection Event) HDF, band interleaved by line (BIL) order
MD1	Step 9	HYP_PREFLIGHT_RX.txt	Summary of pre-flight instrument characterization Text file (MS Word)
MD2	Step 5	EO1YYYYDDD_VVVVSSSS _rX.cal.log	Level 1 calibration log file. Indicates file was calibrated. Text file
MD3 (.L1) MD3A MD3B (.L1_A)	Step 3	EO1YYYYDDD_V'V'V'V'S'S'S'S' _rX.avg	Averaged dark current file (.L1, ave over no. of dark frames acquired) or averaged pre- and post-image dark current files (.L1_A) 256 x 242 pixels, Binary, BSQ (equivalent to BIL for a single frame)
MD5 (.L1) MD5A MD5B (.L1_A)	Step 3	EO1YYYYDDD_V'V'V'V'S'S'S'S'_rX.avg.log	Averaged dark log file, reports average value over all dark pixels for dark file used for dark subtraction (.L1) or Averaged pre-and post-image dark current log files (.L1_A) Text file
MD7	Step 5	HypGain_revA.bin	Calibration coefficient file Binary, BSQ
MD8	Step 2	EO1YYYYDDD_VVVVSSSS _rX.echo.log EO1YYYYDDD_V'V'V'V'S'S'S'S' _rX.echo.log	Echo removal log file, one each for dark and image file. Indicates file was corrected for echo. Text file
MD9	Step 1	EO1YYYYDDD_VVVVSSSS _rX.smear.log EO1YYYYDDD_V'V'V'V'S'S'S'S' _rX.smear.log	Smear correction log file, one each for dark and image file. Indicates file was corrected for smear. Text file

Output (ref. only)	Step in Process	File Name	Data File Description and Format
MD10	Step 6	EO1YYYYDDD_VVVVSSSS _rX.fix.log	Bad pixel replacement log file. Indicates that file was corrected for known bad pixels. The bad pixel locations (band #, sample #) are contained in the log. Text file
MD11	Step 8	EO1YYYYDDD_VVVVSSSS _rX.L1.qa	Image Quality Spot Check Filename No. of frames assessed Operational sensors (VNIR, SWIR) Existence of streaking, banding, shading, saturation, focus problems, line drops Cloud cover Averaged dark file values Text file
MD12	Step 8	EO1YYYYDDD_VVVVSSSS _rX.L1.hdr	ENVI header file
MD 13	Step 9	SpectralL0_revA.1.dat	Full Spectral calibration contains center wavelength for each pixel. 256x242, ascii
MD 14	Step 9	BandWidthL0_revA.1.dat	Full Spectral calibration contains Gaussian full-width-half-maximum for each pixel.256x242, ascii
MD 15	Step 0	EO1YYYYDDD_VVVVSSSS _rX.sat	File containing location (band,sample,frame) of pixel values >4095 for echo, smear and image file Text file
MD 16	Step 9	00indexHYXXXX	Listing of Level 1 DLT tape contents for tape number HYXXXX Text file
MD 17	Step 7	EO1YYYYDDD_VVVVSSSS_r1_XXX.aln.log	VNIR/SWIR co-registration log file, Indicates L_1B file was co-registered. Text file

3.5.2 Description of Quality Assessment Form

MD11 is a Quality Assessment form, shown in figure 14, which is filled out manually and after inspection of a portion of the DCE using ENVI. The form indicates the file name of the scene being examined, and which specific frames were used in the assessment. The beginning of the image is frame 1, and there are ~220 frames per second of image. The form also indicates the number of the DLT tape on which the Level 0 data was received from GSFC, and which sensors were operational for the image. For virtually all DCEs, both sensors are operational. "Operational", however does not necessarily mean that the SWIR was at the proper operational temperature. The average dark value can be used as a rough reference; the cooler on/off schedule can also be used as a rough reference. The true reference is the SWIR FPE temperature that is contained in the HDF Level 0 file described in section 3.4.3. The mnemonic is YSWIRFPET and the Hyperion SWIR is at the proper operational temperature when the SWIR FPE temperature is -153.5 $\pm$ 1C.

The quality check is a qualitative assessment performed using ENVI as a visualization tool. The "band animation" feature in ENVI is used to quickly examine all of the bands in the segment of the image being assessed. Any "unusual" bands are then examined in more detail. Several specific qualities are checked:

Streaking	indicating residual unevenness across the FOV pixels
Banding	indicating unevenness as the image is scrolled along the time dimension
Shading	indicating responsivity roll-off at the edges of the image
Saturation	indicating existence of saturated pixels
Focus	indicating any out-of-focus areas on either focal plane
Linedrops	indicating a line or set of lines in the vertical (FOV) or horizontal (time) directional where pixels were temporarily dead or hot (known bad pixels are repaired).

In general, streaking and linedrops are the only characteristics that are noticed. Streaking can occur in the VNIR or the SWIR. It is a result of slight variations in the pixel-to-pixel calibration in the cross track direction. This is discussed further in chapter 4. The linedrops is generally limited to cases in which it is believed that the South Atlantic Anomaly influences Hyperion.

There are some cases in which saturation may occur. For the SWIR this may occur for very hot targets such as gas flares or active volcanoes. The VNIR has been seen to saturate on rare occasion in scenes with very bright clouds. The saturation limit for the VNIR and SWIR has been studied and is consistent with pre-flight characterization.

The remaining categories are not topically present.

An "X" in the box under SWIR indicates that the quality being assessed, e.g., "streakiness: unevenness across the FOV", was observed somewhere within the first 660 frames of the SWIR image. The average dark file value is reported from MD5.

MD11 - EO12000999_01CD01CC_r1.L1.qa

```
File name:        EO12000147_01CD01CC_r1.L1
Frames assessed:  1-660
Source tape ID:   EO1189
Sensors operational:  [X] VNIR  [X] SWIR

1.0 Image Quality Check
.......VNIR                          SWIR    Comments
    1.1 Streaking                     [ ]  [x]     none
    1.2 Banding                       [ ]  [ ]
    1.3 Shading across FOV            [ ]  [ ]
    1.4 Saturation                    [ ]  [ ]
    1.5 Focus                         [ ]  [ ]
    1.6 Linedrops                     [ ]  [ ]

2.0 Radiometric Calibration
    2.1 Averaged dark file value:  523.6

3.0 Additional Comments
```

Figure 14: MD 11: Quality Assessment Form

3.5.3 Description of Sample Metadata Files

This section describes the contents of sample metadata files. Once the user is familiar with the structure of the metadata file, the user should be able to gain information from all of the metadata files.

The first three lines of a log file identify the Level 1 processing command from which the log file was generated, the Hyperspectral Image Processing (HIP) software version number, and date and time file was processed. In this case, the command used to create the file is "cubeavg", version 1.1 of HIP was used and the level 1 processing was performed on June 5, 2000.

The next set of information contains the command line arguments as well as file parameters associated with the input (source) and output files. The file parameters include the file name, file type, dimensions, data type, byte order (big-endian), and pixel order (BIL or BSQ)) are given for each input and output file. The file name includes the pathname in the level 1 processing system. When appropriate the metadata file will include command line options.

The end of a log file contains processing "Results" or "Summary" information. In this case, the file is reporting the average dark pixel value for the dark file used in the dark subtraction process. The subtracted dark file is 256 FOV pixels x 242 spectral pixels in size and averaged over ~220 frames. The average dark file is supplied as MD3. The average dark pixel value reported in MD5 represents the average value over all FOV and spectral pixels and is used on the Quality Assessment form (MD11) to track instrument performance.

MD5 – EO12000147_01D101D0_r1.avg.log

```
***** cubeavg *****
HIP 1.1
Mon Jun  5 13:06:10 2000

----- Arguments -----
--source-file=/drb12/archive/level1/ground/EO12000147_01D101D0_r1.echo
--source-type=hyperion
--output-file=/drb12/archive/level1/ground/EO12000147_01D101D0_r1.avg
--output-type=generic
--verbose

----- Source file -----
File name: /drb12/archive/level1/ground/EO12000147_01D101D0_r1.echo
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 206 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL

----- Output file -----
File name: /drb12/archive/level1/ground/EO12000147_01D101D0_r1.avg
Type:..Generic
Dimensions: 256 pixels x 242 bands x 1 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL
Source: /drb12/archive/level1/ground/EO12000147_01D101D0_r1.echo

----- Summary -----
Average: 523.625

*******************
```

Figure 15 : Example (MD5) - Average Log. MD5A and MD5B have the same format.

The Echo Removal Log (MD8) has the same general format as Average Log (MD5) but it reports that the echo correction process has been completed. At the end of this log file, the specific echo correction file used in the correction process is identified (ratio.txt), along with the number of the band at which echo correction began. The VNIR focal plane covers spectral bands 1-70, so it is expected that echo correction, which is required only in the SWIR, would start at band 71.

MD8 - EO12000147_01CA01C9_r1.echo.log

```
***** hypecho *****
HIP 1.1
Mon Jun  5 13:06:05 2000

----- Arguments -----
--source-file=/drb12/archive/level1/ground/EO12000147_01CA01C9_r1.smear
--source-type=hyperion
--output-file=/drb12/archive/level1/ground/EO12000147_01CA01C9_r1.echo
--output-type=hyperion
--start-band=71
--ratio-file=/dra2/calfiles/ratio.txt
--verbose

----- Source file -----
File name: /drb12/archive/level1/ground/EO12000147_01CA01C9_r1.smear
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 206 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL

----- Output file -----
File name: /drb12/archive/level1/ground/EO12000147_01CA01C9_r1.echo
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 206 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL
Source: /drb12/archive/level1/ground/EO12000147_01CA01C9_r1.smear

----- Ratio file -----
Ratio file: /dra2/calfiles/ratio.txt
Start band: 71

********************
```

Figure 16: Example (MD 8) - Echo Removal Log

The Smear Removal Log (MD9) has the same format as the Echo Removal Log (MD8) but there is no file used in the smear correction process. Again, the band at which smear correction begins is reported. The VNIR focal plane covers spectral bands 1-70, so it is expected that smear correction, which is also only required in the SWIR, would start at band 71.

MD9 - EO12000147_01CD01CC_r1.smear.log

```
***** hypsmear *****
HIP 1.1
Mon Jun  5 13:07:31 2000

----- Arguments -----
--source-file=/drb12/archive/level0/ground/EO12000147_01CD01CC_r1.L0
--source-type=hyperion
--output-file=/drb12/archive/level1/ground/EO12000147_01CD01CC_r1.smear
--output-type=hyperion
--start-band=71
--verbose

----- Source file -----
File name: /drb12/archive/level0/ground/EO12000147_01CD01CC_r1.L0
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 660 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL

----- Output file -----
File name: /drb12/archive/level1/ground/EO12000147_01CD01CC_r1.smear
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 660 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL
Source: /drb12/archive/level0/ground/EO12000147_01CD01CC_r1.L0

----- Options -----
Start band: 71

********************
```

Figure 17: Example (MD 9) - Smear Removal Log

The Pixel Repair Log (MD10) has the same initial format as the preceding metadata files but it reports on the repair of known bad pixels. The specific file used to identify the known bad pixels is identified (badpix.txt). The results provided in this metadata file are in two parts. The first part, "Bad Pixels", identifies the known bad pixels, by band or spectral pixel number and sample or FOV pixel number, and is essentially a printout of badpix.txt. This file will be updated over the course of the mission. The second, "Results", section indicates how the values of these known bad pixels are replaced. For FOV locations other than 1 or 256, the value is replaced by an average of the value in the neighboring FOV pixels (e.g., 50% of (61, 92) and 50% of (61,94) for bad pixel (61, 93)). FOV pixels 1 and 256 are replaced by the value of the neighbor pixel, 2 or 255.

MD10 - EO12000147_01CD01CC_r1.fix.log

```
***** cubefix *****
HIP 1.1
Mon Jun  5 13:08:29 2000

----- Arguments -----
--source-file=/drb12/archive/level1/ground/EO12000147_01CD01CC_r1.cal
--source-type=hyperion
--output-file=/drb12/archive/level1/ground/EO12000147_01CD01CC_r1.L1
--output-type=hyperion
--bad-file=/dra2/calfiles/badpix.txt
--verbose

----- Source file -----
File name: /drb12/archive/level1/ground/EO12000147_01CD01CC_r1.cal
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 660 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL

----- Output file -----
File name: /drb12/archive/level1/ground/EO12000147_01CD01CC_r1.L1
Type:..Hyperion
Dimensions: 256 pixels x 242 bands x 660 frames
Data type: 16-bit unsigned integer
Byte order: big
Pixel order: BIL
Source: /drb12/archive/level1/ground/EO12000147_01CD01CC_r1.cal

----- Bad pixels file -----
File name: /dra2/calfiles/badpix.txt

----- Bad pixels (band, sample)---

 1, 1
2, 1
3, 1
4, 1
5, 1
6, 1
7, 1
8, 1
9, 1
10, 1
11, 1
12, 1
13, 1
14, 1
15, 1
16, 1
17, 1
18, 1
19, 1
20, 1
21, 1
22, 1
23, 1
24, 1
25, 1
26, 1
27, 1
28, 1
29, 1
30, 1
31, 1
32, 1
33, 1
34, 1
35, 1
61, 93
```

```
72, 95
94, 93
99, 92
116, 138
168, 256
169, 23
190, 113
200, 8
201, 8
203, 115

    ----- Result -----
    (1, 1): 100% of 2
    (2, 1): 100% of 2
    (3, 1): 100% of 2
    (4, 1): 100% of 2
    (5, 1): 100% of 2
    (6, 1): 100% of 2
    (7, 1): 100% of 2
    (8, 1): 100% of 2
    (9, 1): 100% of 2
    (10, 1): 100% of 2
    (11, 1): 100% of 2
    (12, 1): 100% of 2
    (13, 1): 100% of 2
    (14, 1): 100% of 2
    (15, 1): 100% of 2
    (16, 1): 100% of 2
    (17, 1): 100% of 2
    (18, 1): 100% of 2
    (19, 1): 100% of 2
    (20, 1): 100% of 2
    (21, 1): 100% of 2
    (22, 1): 100% of 2
    (23, 1): 100% of 2
    (24, 1): 100% of 2
    (25, 1): 100% of 2
    (26, 1): 100% of 2
    (27, 1): 100% of 2
    (28, 1): 100% of 2
    (29, 1): 100% of 2
    (30, 1): 100% of 2
    (31, 1): 100% of 2
    (32, 1): 100% of 2
    (33, 1): 100% of 2
    (34, 1): 100% of 2
    (35, 1): 100% of 2
    (61, 93): 50% of 92 and 94
    (72, 95): 50% of 94 and 96
    (94, 93): 50% of 92 and 94
    (99, 92): 50% of 91 and 93
    (116, 138): 50% of 137 and 139
    (168, 256): 100% of 255
    (169, 23): 50% of 22 and 24
    (190, 113): 50% of 112 and 114
    (200, 8): 50% of 7 and 9
    (201, 8): 50% of 7 and 9
    (203, 115): 50% of 114 and 116



    ----- Summary -----
    30360 pixels fixed out of 40888320 (0.074251%)

    ******************
```

Figure 18: Example (MD 10) – Pixel Repair Log

```
***** hyp_co_align *****
HIP 1.1
Thu Nov 15 17:31:21 2001

----- Arguments -----
--source-file=EO1E51b/hyp/20013071759_SGS/EO10100602001307111PP/EO12001307_6A8D6A8C_r1_SGS_01.fix
--output-
file=EO1E51b/hyp/20013071759_SGS/EO10100602001307111PP/EO12001307_6A8D6A8C_r1_SGS_01.L1_B
--output-cubename=Hyperion L1

----- Source file -----
File name:        EO1E51b/hyp/20013071759_SGS/EO10100602001307111PP/EO12001307_6A8D6A8C_r1_SGS_01.fix
Type: ..                                                                                    Hyperion
Dimensions:                                                  256 pixels x 242 bands x 6702 frames
Data type:                                                                          16-bit integer
Byte order:                                                                                   big
Pixel order:                                                                                  BIL

----- Output file -----
File name:       EO1E51b/hyp/20013071759_SGS/EO10100602001307111PP/EO12001307_6A8D6A8C_r1_SGS_01.L1_B
Type: ..                                                                                    Hyperion
Dimensions:                                                  256 pixels x 242 bands x 6702 frames
Data type:                                                                          16-bit integer
Byte order:                                                                                   big
Pixel order:                                                                                  BIL
Source:           EO1E51b/hyp/20013071759_SGS/EO10100602001307111PP/EO12001307_6A8D6A8C_r1_SGS_01.fix
```

Figure 19: Example (MD 17) – VNIR/SWIR Co-registration Log

The VNIR/SWIR Co-registration Log (MD`7) has the same format as the Smear Removal Log (MD9).

4 HYPERION DATA CUBE DETAILS

This chapter reviews in more detail the characteristics of the Hyperion data set. The topics include the absolute calibration file as well as a description of the pixel-to-pixel variation, the use of the spectral calibration file and the alignment of the VNIR and SWIR focal planes. The subsequent chapter, Chapter 5, discusses the end-to-end measurement error.

4.1 Absolute Radiometric Calibration

The absolute radiometric calibration and related topics is presented in the section. The derivation and the verification of the calibration file are highlighted.

4.1.1 Derivation of the Absolute Radiometric Calibration File

The absolute radiometric calibration file generated on July 1, 1999 was used as the baseline on-orbit calibration file. The calibration file used by the Level 1_A code is HypGain_revA and that used by Level 1 code is HypGain. The difference between HypGain and HypGain_revA is the method used in generating the pre-flight calibration file. In both cases the solar calibration data collected on Day-of-Year 47 of year 2001 was used to remove pixel-to-pixel variations. The solar calibration collection was also used to improve the VNIR-SWIR overlap region for HypGain_revA. The calibration file is used to process all Level 1 data files. Updates to the calibration file, if required, will be accompanied with an explanation of the update and will be assigned a new revision designator.

4.1.2 Verification of the Absolute Radiometric Calibration

The absolute performance verification plan cross-checked radiance measurements from three different paths: solar calibration, internal lamp calibration source and Lake Frome vicarious calibration effort.

For the solar calibration comparison, the sun's irradiance based on the Hyperion measured radiance was compared with solar irradiance models in the literature. The agreement was within 2% in the VNIR and 5-8% in the SWIR.

The in-flight calibration lamp was used as a ground-to-on-orbit transition. The lamp results indicated the change in responsivity was less than 3% in the VNIR and 5-8% in the SWIR.

Vicarious calibration using Lake Frome in Australia was incorporated into the performance verification of the Hyperion imaging spectrometer instrument. The ground reflectance measurements and atmospheric correction leading to Top of the Atmosphere (TOA) radiances are consistent with the Hyperion ground and solar calibration at the 5 % level in the 450 to 850 nm spectral range. The SWIR agreement is 10 % to 15 %.

The efforts generally indicated the VNIR was within the accuracy of the measurement. The SWIR was within the accuracy of the comparisons. However, the SWIR results consistently indicated a lower response.

4.2 Radiometric Calibration – Advanced Topics

Discussions of the SWIR operational temperature, pixel-to-pixel improvements, and optical scatter is provided for the more advanced user. Also presented is the saturation limit of the instrument and the rationale behind the VNIR and SWIR multiplication factors for level 1 processing.

4.2.1 Proper Operation Temperature of the SWIR

The SWIR-FPE temperature varies from DCE to DCE within the temperature range mentioned above. The responsivity of the SWIR is weakly sensitive to SWIR FPE temperature within this range. The variation due to temperature sensitivity is included in the repeatability estimate and applies to temperature variations in the range of 153.5 C ± 1 C.

4.2.2 Pixel-to-Pixel Variations

The on-orbit calibration file was field flattened based on the solar calibration event that took place on Day of year 47 of 2001. The pixel-to-pixel variations, which are constant throughout a DCE, may vary slightly from DCE to DCE. All of the scenes are being field flattened based on the Day of year 047, 2001 solar calibration.

4.2.3 Optical Scatter

During the processing of the raw VNIR solar calibration data after dark field removal, the existence of an additional offset in the dark field appeared at wavelengths in the very blue (< 400 nm) and the infrared (< 950 nm). It was noticed because there was obviously no real spectral signal in the dark corrected counts. The effect was not noticed at spectral pixels in the mid-wavelength range where the solar response is strong. The size of the scatter for a solar calibration data collection is on the order of 70 counts in the VNIR and 10 counts in the SWIR. The effect of

scatter has been estimated and is included in the error budget. It should be noted that the when the cover is closed, there is no measurable light leakage into the instrument.

4.2.4 Saturation

VNIR saturation occurs on rare occasions on the top-of-clouds over a limited spectral extent. SWIR saturation has been limited to hot spots resulting from gas flares or volcanoes. The revised level 1 processing, Level 1_A, flags saturated pixels. It should be noted that the SWIR echo and smear algorithms cannot remove the artifact when the source pixel is saturated.

4.3 Spectral Calibration

The derivation and verification of the spectral calibration file is discussed.

4.3.1 Spectral Calibration files

The spectral calibration for Hyperion is described by a Gaussian bandpass and is defined by a center wavelength and full width half maximum defined by SpectralL0_RevA.1 and BandwidthL0_RevA.1, respectively. Both files are provided with the level 1 processed data set. The size of each file is 256x242 since the spectral calibration is extended for every pixel in the VNIR and SWIR focal plane. The bandwidth of each pixel is approximately 10 nm.

The spectral calibration supplied by SpectralL0_RevA.1 and BandwidthL0_RevA.1 is presented as images below, Figure 19 and 20 respectively. Although not evident in the image of the SpectralL0_revA there is a variation of the center wavelength across the field of view that should be taken into account in certain applications. Figures 21 and 22 show the variation across the field of view for selected VNIR and SWIR wavelengths. The wavelengths selected span the calibrated range of wavelengths and should give the user a sense for the variation for the entire focal plane. The variation of the spectral smile is smaller for the SWIR than it is for the VNIR.

The spectral calibration is applicable for the life of the mission.

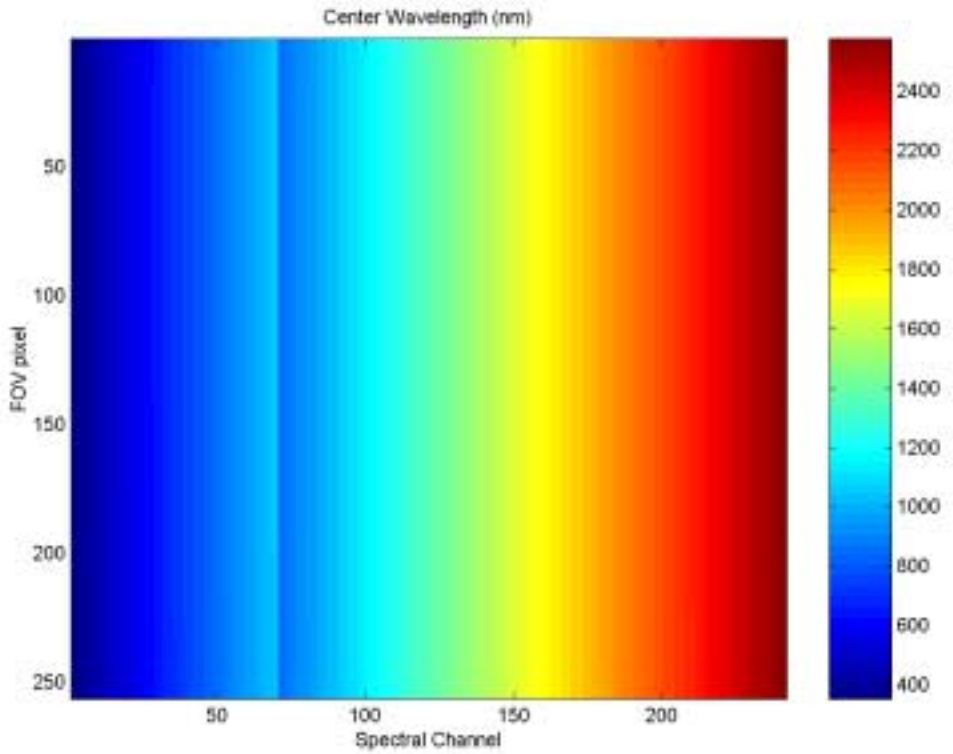

Figure 20: Image of the Center Wavelength Calibration File

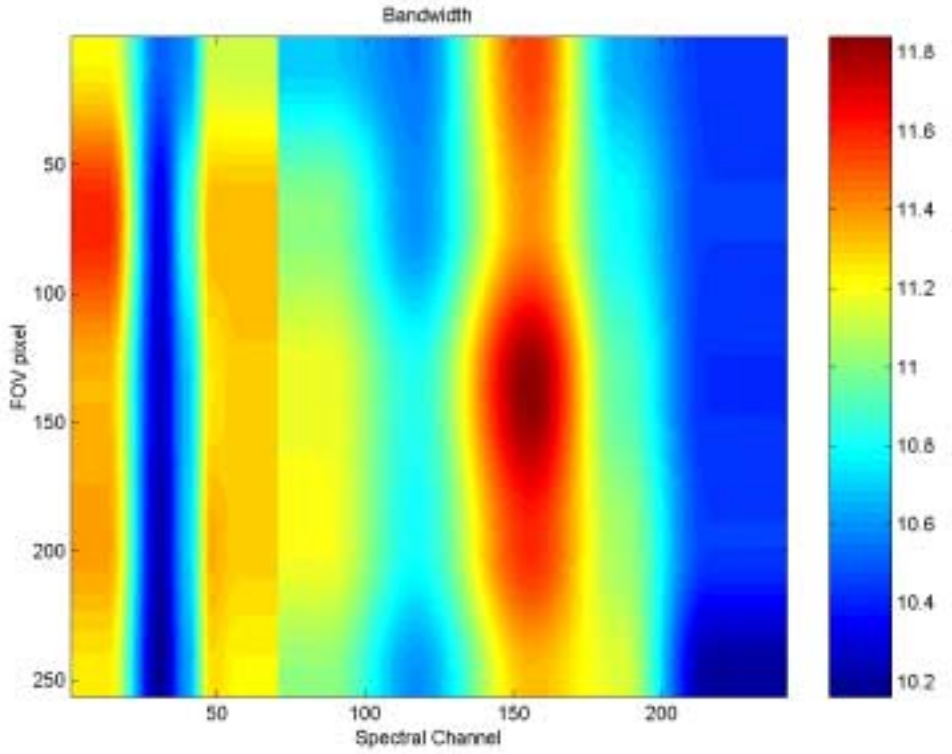

Figure 21: Image of the Full Width Half-Maximum Calibration File

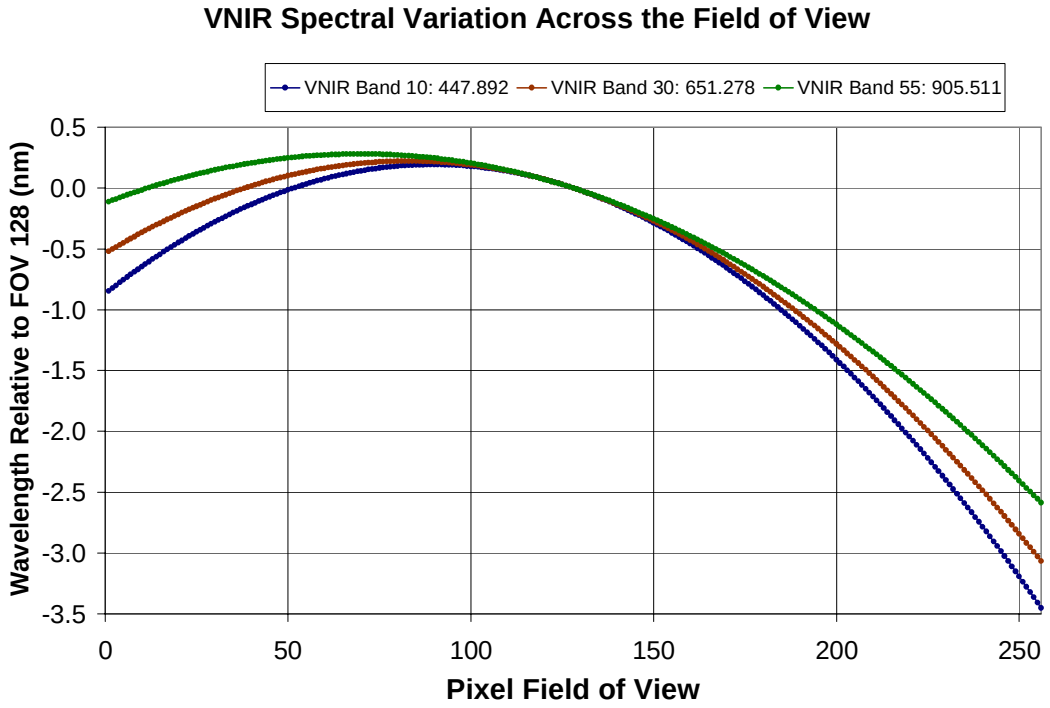

Figure 22: Variation of the VNIR center wavelength across the field of view

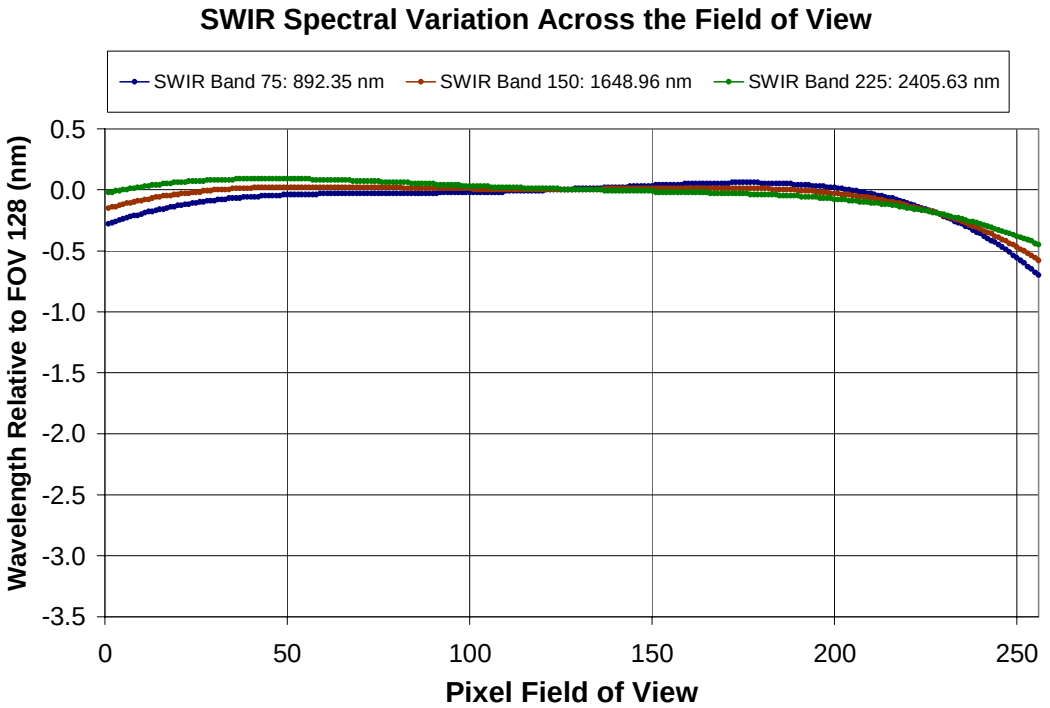

Figure 23: Variation of the SWIR center wavelength across the field of view

4.3.2 Verification of Spectral Calibration Files

A data collection and analysis process to validate the spectral calibration of Hyperion from space was developed. The process was based on a solar data collect and an atmospheric limb data collect in which the rays of the sun passing through the atmosphere and reflecting off the Hyperion cover were used. The results for the SWIR and VNIR wavelengths confirm that the Hyperion pre-flight spectral calibration is valid for on-orbit operations. As a result the pre-flight spectral calibration defined by SpectralL0_revA and BandwidthL0 were approved for on-orbit operation. The revision for the center wavelength was based on a revised analysis of the pre-flight data.

4.3.3 Spectral Wavelengths Selected for Absolute Radiometric Calibration

As mentioned earlier, the size of the Hyperion Level 0 and Level 1 data set has the dimension 256x6925x242. However, of the 242 spectral channels, 204 channels are selected for calibration. The reduction is partly due to insufficient signal at the extremes of the spectral range and partly due to existence of an overlap region between the VNIR and SWIR. The bands that are not calibrated are set to zero. The user will notice a signal in the Level 0 data, and will see a value of zero for those bands that are not calibrated in the level 1 processed data.

The range of calibrated spectral channels is different between HypGain and HypGain_revA and is listed in the table below.

	HypGain	HypGain_revA
VNIR: bands (nm)	9-57 (437-925)	5-57 (400-925)
SWIR: bands (nm)	75-225 (890-2400)	75-225 (890-2400)
Calibrated channels	200 (4 overlap)	204 (4 overlap)
Unique Channels	196	200

This results in 204 calibrated channels with 200 unique wavelengths provided in the .L1_A data file. Four bands in the VNIR (54-57) overlap with four bands in the SWIR (75-78), which is 892 to 926 nm. The selection of bands for science applications is left to the discretion of the user.

4.3.4 Quick Look Spectral Wavelength in the Header File

The level 1 data product includes in the header file a center wavelength and a full-width-half maximum value for a Gaussian shape. The values are applicable for field of view pixel 128. It can be used for quick look plots but should not be used for science applications.

4.4 VNIR – SWIR Spatial Alignment- Advanced Topics, Level 1 and Level 1_A Data Products Only

4.4.1 Ground Sample Distance

The ground sample distance for the VNIR and SWIR focal planes was determined to be 30.67 meters in the cross-track direction and 30.56 meters in the along track direction for each pixel. The swath width is spanned by 256 field of view locations and there are 242 spectral channels for each field of view location. This results in 61,952 different pixels. The complexity is that

each pixel in the VNIR and SWIR view a slightly different portion of the ground in a single instance.

4.4.2 VNIR and SWIR Spatial Co-registration of Spectral Channels

The spatial co-registration is a measure of an object's position in the FOV as a function of the spectrometer wavelength. The spatial co-registration for the VNIR is better than 0.25 pixels. The spatial co-registration for the SWIR is better than 0.28 pixels in the spectral direction. This characterization treats each focal plane as separate units.

4.4.3 Co-registration between the VNIR and SWIR

It is understood that the user may have the desire to look at the entire spectrum for a single spatial location. In order to do this, the spatial co-registration between the VNIR and the SWIR becomes important. There is a difference between the VNIR-to-SWIR co-registration for the cross-track and in-track direction. For the cross-track direction, there is a one pixel offset between the VNIR and SWIR. So pixels 1-255 in the VNIR correspond to field-of-view pixels 2-256 in the SWIR. The difference in the in-track direction is a little more complicated. The difference is dependent on the field-of-view location. The in-track difference is zero for field of view pixel 1. The in-track difference decreases linearly to -1 for field-of-view pixel 256.

5 END TO END MEASUREMENT ACCURACY

Table 9 shows the absolute and precision errors for a single measurement of a scene element by Hyperion. The top of the atmosphere radiance measurement error of a scene by a given single pixel at a given spatial location and spectral wavelength is the result of the combination of an absolute bias (systematic) error and a precision error.

Table 9: Hyperion End-to-End Measurement Error

Total Measurement Error			**VNIR**	**SWIR**
			2.95	**3.39**
	VNIR	**SWIR**		
Precision Error (from Precision table)	**1.60**	**2.30**		
Absolute (Systematic) Bias	**2.49**	**2.49**		

Appendix 1: L1readme_r3

This file documents changes to the Hyperion Level 1 processing system and shows the differences between Level 1 data products. The hyperlinks will show specific changes to a file or changes in the Level 1 data product.

Effective Date	L1 file	Ratio file	Gain file	VNIR Cal Mult	SWIR Cal Mult	Cal Min	Cal Max	Bad pixel file	Description of modification
1-Apr-01	.L1	ratio.txt	hypgain.bin	100	100	0	65536	badpix2	See following pages
1-Jul-01	.L1_A	ratio_revA.txt	HypGain_revA.dat	40	80	-32768	32768	badpix2	See following pages
12-Oct-01	.L1_A1	ratio_revB.txt	HypGain_revA.dat	40	80	-32768	32768	badpix3	See following pages
16-Oct-01	.L1_A2	ratio_revB.txt	HypGain_revB.dat	40	80	-32768	32767	badpix3	See following pages
23-Oct-01	.L1_A3	ratio_revB.txt	HypGain_revB.dat	40	80	-32768	32767	badpix3	See following pages
15-Nov-01	.L1_B	ratio_revB.txt	HypGain_revB.dat	40	80	-32768	32767	badpix3	See following pages

Level 1 Processing Change Summary

Level 1 version	.cal	.L1	.L1_A	.L1_A1	.L1_A2	.L1_A3	.L1_B
Effective date	pre-flight	4/1/2001	7/1/2001	10/12/2001	10/16/2001	10/23/2001	TBD
Level 1 parameters mods							
Ratio file	ratio.txt	ratio.txt	ratio_revA.txt	ratio_revB.txt	ratio_revB.txt	ratio_revB.txt	ratio_revB.txt
Gain file	PriRadL0.bin	hypgain.txt	HypGain_revA.dat	HypGain_revA.dat	HypGain_revB.dat	HypGain_revB.dat	HypGain_revB.dat
Data type	uint16	uint16	int16	int16	int16	int16	int16
Calibration multiplier VNIR	100	100	40	40	40	40	40
Calibration multiplier SWIR	100	100	80	80	80	80	80
Cal Min	0	0	-32768	-32768	-32768	-32768	-32768
Cal Max		40000	32768	32768	32767	32767	32767
Bad pixel file	badpix	badpix2	badpix2	badpix3	badpix3	badpix3	badpix3
Level 1 algorithm mods							
Bad pixel repair	yes	yes	yes	yes (update)	yes	yes	yes
Saturated pixel report	no	no	yes	yes (update)	yes (update)	yes (update)	yes (update)
Offset removal	nearest in time	nearest in time	interpolated in time	interpolated in time	interpolated in time	interpolated in time	interpolated in time (update)
VNIR/SWIR co-alignment	no	no	no	no	no	no	yes

change from previous version
yes=included in level 1 version
no=not included in level 1 version

Level 1 Processing Change Record

Level 1 version	Parameter or Algorithm	Description of Change
.L1	**Ratio file**	ratio.txt was derived from pre-flight instrument characterization
	Gain file	hypgain.bin was derived from pre-flight instrument characterization
	Data Type	The data type is a 16-bit unsigned integer ranging from 0-65536.
	Calibration multiplier (VNIR/SWIR)	To maximize precision and reduce file size, the VNIR and SWIR calibrated radiance values are multiplied by 100 and stored as integers.
	Cal Min-Max	Minimum and maximum calibrated radiance values are based on the range of 16-bit unsigned integers (0-65536). The cal min-max values cut off radiance values < zero at 0 and values > 65536 are truncated at 65536.
	Bad pixel file	Sample number 1 for VNIR bands 1-35 were added to the bad pixel file (badpix2).
	Bad pixel repair	*Cubefix* replaces a bad pixel with the average of the two adjacent (FOV) pixels. If a dead pixel is on the edge of the FOV (sample 1 or 256) then 100% of the adjacent pixel (sample 2 or 255) value replaces the dead pixel.
	Saturated pixels	Not reported
	Offset removal (dark cal)	The dark subtraction is performed using an average of all frames of a dark file that was acquired closest in time to the image.
	VNIR/SWIR co-alignment	Not included
.L1_A	**Ratio file**	The ratio_revA.txt is an improved estimate of the correction factor in regions where signal levels in the data were very low.
	Gain file	Hypgain_RevA.dat adds bands 5-8 (400 - 430 nm) to the L1_A data for a total of 204 calibrated bands. The agreement between bands of the overlap region (890-925 nm) has been improved. The dark subtraction process used in the derivation of the pre-flight calibration file was revised. Radiance values in HypGain_revA.dat are generally 1% lower than hypgain.txt except below 550 nm and between 900 - 1100 nm where radiances are more than 1% lower than hypgain.bin.
	Data Type	The data type was changed to a 16-bit signed integer with a range of -32768 / +32768.
	Calibration multiplier (VNIR/SWIR)	The calibration multiplier was changed to retain precision of the maximum radiance (750 W/m2/sr/*u*m VNIR and 350 W/m2/sr/*u*m SWIR) within the range of a 16-bit signed integer (-32768/+32767). The calibrated radiance values are multiplied by 40 for VNIR bands (1-70) and by 80 for SWIR bands (71-242).
	Cal Min-Max	Minimum and maximum radiance values were changed to correspond with the range of a 16-bit signed integer. Calibrated radiance values < -32768 are cut off at -32768 and values > 32768 are truncated at 32768.
	Saturated pixels	The *cubesat* program identifies raw (L0) image pixels with values equal to 4095 and reports their band, sample, and frame numbers to a log file (.sat file extension). The log file also identifies smear and echo affected pixels because these artifacts can not be removed correctly when the source pixel is saturated. The following errors were discovered in the .sat file after the release of L1_A data: 1) the location of saturated pixels in the image file is incorrectly translated into band, sample, and frame number, 2) smear and echo affected pixels are incorrectly reported for VNIR bands (1-70) since these corrections are not applied to the VNIR data. These errors occur in versions L1_A, L1_A1 and L1_A2.
	Offset removal (dark cal)	Dark signal removal for .L1_A data is performed using a dark file value that is interpolated in time between the pre-image dark and post-image dark files. The interpolated values are subtracted from the image on a frame by frame basis.

Level 1 version	Parameter or Algorithm	Description of Change
.L1_A1	**Ratio file**	ratio_revB.txt contains zeros at dead pixel locations to prevent the smear correction to be propagated through the echo correction at these locations.
	Bad pixel file	Added three non-responsive (same value for entire scene) pixels to bad pixel list (badpix3).
	Bad pixel repair	When neighboring pixels contain a positive and a negative value, the dead pixel was incorrectly replaced with values close to +/- 32768. To correct for this error, the method used by cubefix to average adjacent pixels was modified. This mitigated the occurrence of data overflow when taking the average of a positive and negative number.
	Saturated pixels	A modified version of cubesat repairs errors in the translation of saturated pixel locations to band, sample and frame numbers. The modified version accurately reports band and frame number but the sample number is off by plus 1.
.L1_A2	**Gain file**	Hypgain_RevB.dat removes (zeros) bands 5-6-7-75-76 and 225 from the L1_A2 data product.
	Cal Min-Max	In the L1_A and L1_A1 data products, the maximum value (Cal max) of a calibrated pixel was set to +32768 which is not a valid signed integer. (The range of 16-bit signed integers is -32768 to +32767.) Therefore, when a calibrated pixel was greater than +32767 it was given a value of -32768. In the L1_A2 version the Cal max value was changed to +32767 which correctly handles pixel values greater than +32767 (i.e. they are truncated at +32767).
	Saturated pixels	A modified version of cubesat repairs errors in the translation of saturated pixel locations to band, sample and frame numbers. The modified version accurately reports band and frame number but the sample number is off by plus 1.
.L1_A3	**Saturated pixels**	A modified version of cubesat repaired errors in reported sample number of saturated pixels, removed smear and echo affected pixels for VNIR bands (1-70) from the .sat file, and sorts the .sat file by band number.
.L1_B	**Offset removal (dark cal)**	The dark file interpolation algorithm was modified to account for the time between the pre-image dark file and the start of the image.
	Saturated pixels	The saturated pixel report was updated to reflect the spatial shift of SWIR pixel locations as a result of VNIR/SWIR co-alignment. The new report includes saturated pixels locations for the L0 and L1_B data.
	VNIR/SWIR co-alignment	Level 1_B co-registers the VNIR and SWIR data. Only SWIR data are shifted into alignment with the VNIR pixels. In the FOV dimension the SWIR pixels are shifted by -1. In the along track dimension FOV pixels 129-256 are shifted +1 pixel. A new metadata file is generated with a. aln.log extension.

Ratio.txt File Modifications

zeroed pixels	
ratio_revB.txt	
Band	**Sample**
94	23
99	92
116	138
168	256
169	23
190	113
203	115
200	8
201	8

Bad Pixel File History

bad pixel file history

badpix			badpix2			badpix3		
Band	**Sample**	**Status**	**Band**	**Sample**	**Status**	**Band**	**Sample**	**Status**
61	93	dead	1	1	dead	1	1	dead
72	95	dead	2	1	dead	2	1	dead
94	93	dead	3	1	dead	3	1	dead
99	92	dead	4	1	dead	4	1	dead
116	138	dead	5	1	dead	5	1	dead
168	256	dead	6	1	dead	6	1	dead
169	23	dead	7	1	dead	7	1	dead
190	113	dead	8	1	dead	8	1	dead
200	8	dead	9	1	dead	9	1	dead
201	8	dead	10	1	dead	10	1	dead
203	115	dead	11	1	dead	11	1	dead
			12	1	dead	12	1	dead
Status			13	1	dead	13	1	dead
dead - pixel value = 0			14	1	dead	14	1	dead
flat - non-responsive (same value entire			15	1	dead	15	1	dead
scene)			16	1	dead	16	1	dead
new bad pixels			17	1	dead	17	1	dead
			18	1	dead	18	1	dead
			19	1	dead	19	1	dead
			20	1	dead	20	1	dead
			21	1	dead	21	1	dead
			22	1	dead	22	1	dead
			23	1	dead	23	1	dead
			24	1	dead	24	1	dead
			25	1	dead	25	1	dead
			26	1	dead	26	1	dead

bad pixel file history

badpix			badpix2			badpix3		
Band	**Sample**	**Status**	**Band**	**Sample**	**Status**	**Band**	**Sample**	**Status**
			27	1	dead	27	1	dead
			28	1	dead	28	1	dead
			29	1	dead	29	1	dead
			30	1	dead	30	1	dead
			31	1	dead	31	1	dead
			32	1	dead	32	1	dead
			33	1	dead	33	1	dead
			34	1	dead	34	1	dead
			35	1	dead	35	1	dead
			61	93	dead	61	93	dead
			72	95	dead	72	95	dead
			94	93	dead	94	93	dead
			99	92	dead	99	92	dead
			116	138	dead	116	138	dead
			168	256	dead	119	240	flat
			169	23	dead	120	240	flat
			190	113	dead	165	148	flat
			200	8	dead	168	256	dead
			201	8	dead	169	23	dead
			203	115	dead	190	113	dead
						200	8	dead
						201	8	dead
						203	115	dead

Gain File Modifications

zeroed bands		Gain file history	hypgain	HypGain_revA.dat	HypGain_revB.dat
HypGain_revB.dat		Calibrated VNIR : bands (nm)	9-57 (437-925)	5-57 (400-925)	8-57 (427-925)
VNIR	SWIR	Calibrated SWIR: bands (nm)	75-225 (890-2400)	75-225 (890-2400)	77-224 (912-2395)
5	75	Total number of Calibrated bands	200	204	198
6	76	Number of Unique calibrated bands	196	200	196
7	225	Number of VNIR/SWIR overlap bands	4	4	2